TAMPERE UNIVERSITY OF TECHNOLOGY

NATALIA VENCE LINARES

ANALYSIS OF SOLAR WATER HEATING SYSTEMS IN SINGLE FAMILY HOUSES - COMPARISON BETWEEN FINNISH AND SPANISH SITUATION

Master of Science Thesis

Examiner: Professor Timo Kalema

Examiner and topic approved in the Faculty of Automation, Mechanical and Materials Engineering Council meeting on 6th April 2011

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Natalia Vence Linares

“Eres capaz de todo, sólo tienes que proponértelo”

(You are capable of everything; you just have to go for it)

Abstract

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VENCE LINARES, NATALIA: Analysis of solar water heating systems in single family houses - Comparison between Finnish and Spanish situation
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Keywords: solar energy, irradiation, thermal solar installation, useful solar energy, DHW (domestic hot water), SWH (solar water heating), energy regulations, solar energy situation in Finland, solar energy situation in Spain, solar DHW installation analysis, DHW single family house.

The objective of this thesis is to analyse the useful solar energy that can be obtained in thermal solar installations aimed for domestic hot water (DHW) heating in a single family house. The analysis has been made for two countries with different climate conditions (Finland and Spain). A virtual house has been implemented to have the same characteristics and specifications in both countries, so that the analysis results obtained do not depend on the physical characteristics, but only the climatologic ones.

Firstly, a wide literature research about solar energy, its applications, its installations and systems has been done, for having a consistent theoretical background before the analysis are performed.

Secondly, the climatologic and energetic situation in both countries has been analyzed. Then, the regulations, which for both countries are based on the European directives, have been studied for being able to perform the simulations accordingly.

Then the simulations have been done with the software RETScreen, widely used for renewable installations. The aim of these simulations is to obtain the effects various issues on the total useful solar energy received and the behaviour of the installation when varying the following parameters: the tilt angle of the collectors, the type of collector (either glazed or evacuated tube collectors are used) and the total collector area. All in all, with these analyses, the optimal solution for the solar installation in both countries is pursued.

And in the end, an economical analysis has been performed, to obtain the allowed investment for the optimized solar installation in each country; taking into account the common ways of DHW heating for single family houses.

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Abbreviations and notation

$(\dot{m}C_p)_c$	Collector fluid capacitance rate [J/s K]
$(\dot{m}C_p)_{min}$	The smaller of the fluid capacitance rates [J/s·K]
A_c	Collector area [m^2]
AEMET	Agencia Estatal de Meteorología (National Meteorologic Agency)
A_f	Floor area [m^2]
A_i	Area for heat loss of the inlet duct [m^2]
AM	Air mass [kg]
A_o	Area for heat loss of the outlet duct [m^2]
A_{Tc}	Total collector Area [m^2]
C_p	Specific heat of the fluid [J/kg·K]
CRF	Capital Recovery Factor
CSP	Concentrating Solar Power technologies
CTE	Código Técnico de Edificación (Technical Document for Building)
d	Distance [m]
d_{atm}	Atmospheric thickness [m]
DB	Documento Básico (Basic Document)
DB HE	Documento Básico HE: Ahorro de Energía (Basic Document HE Energy Savings)
DHW	Domestic Hot Water
EU	European Union
F'	Collector efficiency factor
F_R	Collector heat removal factor
G	Irradiance [W/m^2]
G_b	Beam radiation on a horizontal surface [W/m^2]
$G_{b,T}$	Beam radiation on a tilted surface [W/m^2]
G_o	Solar radiation outside the atmosphere on a horizontal plane [W/m^2]
G_{on}	Extraterrestrial radiation, measured on the plane normal to the radiation on the n^{th} day of the year [W/m^2]
G_{sc}	Extraterrestrial solar radiation or solar constant [W/m^2]
h	Height [m]
H	Insolation for a day [J/ m^2]
h_{energy}	Price of the source of energy [€/kWh]
H_g	Global hourly irradiance on earth [J/ m^2]
HHV	Higher Heating Value

HL	Head Loss [J]
H_o	Daily extraterrestrial radiation on a horizontal surface [J/ m^2]
HVAC	Heating, Ventilating and Air Conditioning
i	Interest rate [%]
I	Insolation for an hour [J/ m^2]
$I_{allowed}$	Allowed investment [€]
I_b	Irradiation on a surface with the sun in its zenith [J/ m^2]
$I_{b,n}$	Irradiation on a horizontal surface [J/ m^2]
$I_{b,T}$	Irradiation on a tilted surface [J/ m^2]
I_d	Diffuse irradiation [J/ m^2]
$I_{d,T}$	Diffuse irradiation on a tilted surface [J/ m^2]
IDA	Diversificacion y Ahorro de la Energía (Institute for Diversification and Saving of Energy)
IEA	International Energy Agency
I_o	Hourly extraterrestrial radiation on a horizontal surface [J/ m^2]
IR	Infrared
I_T	Total or Global radiation [J/ m^2]
K	Clearness index
k	Dimensionless coefficient
K_D	Diffusion index
LHV	Lower Heating Value
m	Mass [kg]
$\dot{m}$	Flow rate [kg/s]
MICyT	Ministerio de Industria, Turismo y Comercio (Ministry of Industry, Tourism and Trade)
Mtoe	Million tonnes of oil equivalent
N	Number of daylight hours
n	Day of the year
NTU	Number of Transfer Units
OECD	Organisation for Economic Co-operation and Development
ORC	Organic Rankine Cycle
OTEC	Ocean Thermal Energy Conversion
Q_{HX}	Heat exchanger performance
Q_s	Stored heat inside the tank [J]
Q_{saving}	Energy saved by the renewable installation [kWh]
Q_u	Actual useful energy gain of a collector [J]
R	Radius of the sun [m]
R_b	Ratio of beam radiation on the tilted surface to that on a horizontal surface at any time
RTD	Resistance Temperature Detector
S	Absorbed solar radiation [J/ m^2]

SWH	Solar Water Heating
T_a	Ambient temperature [K] or [ºC]
$T_{c,o}$	Outlet fluid temperature from the collector [K] or [ºC]
T_{db}	Dry-bulb temperature [K] or [ºC]
$T_{f,i}$	Inlet fluid temperature [K] or [ºC]
$T_{f,o}$	Outlet fluid temperature [K] or [ºC]
T_i	Inlet water temperature to the heat exchanger [K] or [ºC]
toe	Tonne of oil equivalent
U_d	Loss coefficient from the duct [$W/m^2 \cdot C$]
U_L	Collector overall loss coefficient [$W/m^2 \cdot C$]
UV	Ultraviolet
V_s	Volume of the storage device [l]
α_s	Solar height [º]
β	Collector's tilting [º]
β_{3A}	Tilt of a solar panel for 3A tracked solar panels [º]
β_{max}	Maximum tilting [º]
β_{min}	Minimum tilting [º]
β_{opt}	Optimum tilting [º]
β_{optM}	Optimum tilting for Madrid [º]
β_{optT}	Optimum tilting for Tampere [º]
γ	Surface azimuth angle [º]
γ_s	Solar azimuth angle [º]
δ	Declination [º]
ΔT	Temperature difference
ε	Heat exchanger effectiveness
θ	Angle of incidence [º]
θ_z	Zenith angle [º]
ρ	Albedo or reflectance
φ	Latitude [º]
φ_a	Azimuth angle of 3A tracked solar panels in the morning and afternoon from the due south [º]
φ_r	Real Latitude [º]
ω	Hour angle [º]
ω_a	Solar hour angle when azimuth angle adjustment of solar panels is made in the morning and afternoon [º]
ω_s	Sunset hour angle [º]

1 Introduction

1.1 Introduction

Spain and Finland, as European countries, do not have many differences: same currency, developed country, democracy, etc. But climatologically talking they are not lookalike. This is one of the reasons why in this thesis those countries are compared, because they are the representatives of the extreme climate situations in Europe.

In this thesis is covered all the theoretical background needed about the solar energy, from the sun's core reactions till the last heat exchanger that makes possible to have current hot water in the tap. A wide research has been done about the solar radiation received by a horizontal surface, the different solar technologies existing nowadays, the types of solar installation that uses the sun's energy for different purposes, the domestic hot water (DHW) systems, and the DHW installations and its components. All of this for having a base on which fundament and be able to make the analyses that are going to be performed.

But before jumping on to the analyses, is important to know and learn the climatologic conditions in each country, and how they interfere with the sun rays. And not only is the climatological conditions the important issue, so it is the energetic situation in each country. As Finland and Spain both are members of the European Union (EU), they must update their regulations for fulfilling the requirements of the EU, via European Directives. The member States have made a commitment to achieve the "20-20-20 goal", which consist in reducing the consumption of primary energy by 20% by 2020.

Accordingly, Finland and Spain are looking for new ways for obtaining energy, and here appears the need of installing new systems to use the biggest free source of energy called Sun. In this thesis a thermal solar installation in a single family house in Finland and in Spain is going to be studied. These houses do not exist in real life; a virtual house will be considered for both countries. This virtual house will have exactly the same physical characteristics and specifications in each country. However, the only difference is going to be the climatological condition which is so different in Spain and Finland.

Once the virtual house is defined, the simulations can be done. These simulations will be performed with a software programme used widely for renewable installations: RETScreen. Hence, one of the objectives of this thesis is to learn and become a user of this computer tool.

In this thesis various analyses have been done: a first simulation for dimensioning the virtual houses and their heating needs, which is non renewable, and the rest of the simulations will be over the solar thermal installation. About it, the optimum tilting of the collectors will be deduced for obtaining the maximum useful solar energy. Also, a comparison of the thermal system between having installed glazed and evacuated tube collectors will be performed. And for each type of collector, the optimum total collector area will be obtained, by iteration.

After the optimal solution is achieved for each country, an economical analysis will be done. In it, the allowed investment for each installation in each country will be calculated. For this analysis, the common energy used for heating in each country will be considered, so the study will be more realistic, and the allowed investment more trustful.

Finally, with all the results obtained from the analysis, the conclusions about the useful solar energy, the optimum tilting and the best collector configuration (type and area) in each case will be obtained.

1.2 Objectives

The objectives of this thesis are:

- Gain knowledge about the sun as a source of energy.
- Learn and understand how to calculate the radiative energy provided by the sun.
- Gain knowledge of different technologies for capture and collect solar energy.
- Understand how a thermal solar system work, and its components.
- Learn and study the regulations for solar installations in Europe in general, and specifically in Finland and Spain.
- Learn and become a user of RETScreen software.
- Analyze which is the best tilting of the collectors for obtaining the maximum useful solar energy.
- Compare, for the same needs of a model single family house, the benefits and disadvantages of using different collectors and different collector surface.
- Compare and analyze the useful solar energy obtained in each country for a thermal solar installation for DHW heating in a single family house in Finland and in Spain.
- Perform an economics analysis to obtain the allowed investment for each installation, considering the energy situation of each country.

2 Theoretical approach of solar energy installations

2.1 Definition of solar energy

Earth's surface receives energy from processes in Earth's interior and from the sun[1]. The heat from the interior is a result of the radioactive elements in the mantle[2] and core, tidal[3] produced by the Moon and sun, and residual heat from the earth's formation. This interior heat is radiated through the surface at a global rate of 3·1013 W (about 0,06 W/m^2). The sun, in contrast, provides 1,73·1017 W, 5.700 times more power than Earth radiates from within and about 30.000 times more than is released by all human activity. However, clouds, air, land, and sea absorb 69% of the energy arriving from the Sun and reflect the rest back into space. On the other hand, the ocean, which covers about 70% of the earth's surface, does about 70% of the absorbing of solar energy.

Between its absorption as heat and its final return to space as infrared radiation[4], solar energy takes many forms, including kinetic energy in flowing air and water or latent heat[5] in evaporated water. Solar energy keeps the oceans and atmosphere from freezing and drives all winds and currents. A small fraction of Earth's solar energy income is intercepted by green plants, providing the flow of food energy that sustains most earthly life. Only a few organisms, including thermophilic[6] bacteria infiltrating the crust and organisms specialized to live in the vicinity of hydrothermal deep-sea vents[7], derive their energy from Earth's interior rather than from the sun.

1 In the next subchapter the sun's energy is explained broadly.

[2] Mantle: Layer of the Earth between the crust and the core, which extends to a depth of 2890km. The mantle forms the greatest bulk of the Earth: 82% of its volume and 68% of its mass (World Encyclopedia, 2005). The three Earth's layers are: crust, mantle and core.

[3] Tidal Heating: is the generation of heat due to friction produced by the strong tidal forces exerted by a very massive parent body on a body moving about it in an elliptical orbit. The intensity of tidal heating is proportional to the square of the orbital eccentricity, being zero in a circular orbit and reaching a maximum in a parabolic orbit, and inversely proportional to the size of the orbit (Allaby & Allaby, 1999).

[4] Infrared radiation (IF): is the portion of the electromagnetic spectrum that extends from the long wavelength, or red, end of the visible-light range to the microwave range. It is invisible to the eye, although it can be detected as a sensation of warmth on the skin (Enciclopaedia Britannica, 2011).

[5] Latent heat: characteristic amount of energy absorbed or released by a substance during a change in its physical state that occurs without changing its temperature (Enciclopaedia Britannica, 2011).

[6] Thermophilic: Describing an organism that lives and grows optimally at extremely high temperatures, typically over 40°C (A Dictionary of Biology, 2004).

[7] Hydrothermal vents: are hot springs located on the ocean floor. The vents spew out water heated by magma, molten rock from below the earth's crust (Swain, 2003).

Regional variations in solar input contribute to weather patterns and seasonal changes. On average Earth's surface is more nearly at a right angle to the sun's rays near the equator, so the tropics absorb more solar energy than the higher latitudes. This creates an energy imbalance between the equator and the poles, an imbalance that the circulation of the atmosphere and oceans restore by transporting energy away from the equator. During each half of the year the daylight side of each hemisphere is tilted at a steeper angle to the sun than during the other half, and so intercepts less solar energy; this results in seasonal climatic changes.

Solar energy is also of technological importance. Utilization of the Sun as an energy source has been routine on spacecraft for decades and is becoming more frequent on the ground. Electromagnetic radiation from the sun, unlike the major conventional power sources, produces no smokestack[8] emissions, greenhouse gases, or radioactive wastes; and its production cannot be manipulated for profit or political leverage. On the down side, sunlight is a diffuse or spread-out energy source compared to any fuel and is directly available only during the day. Yet, even at high latitudes in Europe and North America, where most of the world's energy is consumed, the ground receives from the sun a long term average of 100 W/m^2. This average is inclusive of "dark" hours. Both indirect and direct harvesting of this energy income is possible. Indirect solar schemes, including wind power, wood heat, and the burning of alcohol, methane, or hydrogen, run on energy derived at second hand from sunlight. Direct schemes use sunlight as such to heat buildings or water, generate electricity, or supply high-temperature process heat to industrial systems.

Because conventional electricity generation is expensive and polluting, much effort has been devoted to solar electricity generation. Electricity can be generated from sunlight either thermally or photovoltaically. Thermal methods focus the sun's rays on looped pipes through which molten salt, hot air, or steam flows. This hot fluid is then used either at first or second hand to run generators, much as heat from coal or nuclear fuel is used in conventional power plants. Photovoltaic electrical generation depends on flat, specially designed transistors, solar cells, which convert incident light to electricity. At 100 W/m^2 average solar input, 32 m^2 of 33% efficient solar cells (a square of 5,5 m of side) could supply 800 kilowatt-hours (kWh) of electricity per month, the approximate usage of the average U.S. household. An efficiency of 32,3% has been demonstrated in the laboratory, but most commercial photovoltaic cells are only about 10% efficient. Unlike the unused heat from a ton of coal or uranium, however, the sunlight not converted to electricity by a solar cell entails neither monetary cost nor pollution, and so cannot be viewed as waste.

Despite its obvious advantages, photovoltaic electricity generation has long been limited to specialized off-grid applications by the high cost of solar cells. However, cell prices have fallen steadily, and several large-scale photovoltaic electricity projects are now under way in the U.S. and elsewhere.

(World of Earth Science, 2003)

[8] Smokestack: is a large chimney or vertical pipe through which combustion vapours, gases, and smoke are discharged (Houghton Mifflin Company, 2000).

2.2 Theoretical background

2.2.1 The sun

According to the Encyclopaedia Britannica, the sun is the “Star around which the components of the solar system revolve” and is the dominant body of the system with more than 99% of its mass. It is a 4,6 billion-year-old sphere composed of intensely hot gaseous matter, with a diameter of $1{,}39\cdot 10^{9}$m (Enciclopaedia Britannica, 2011) and is, on the average, $1{,}5\cdot 10^{11}$m from the Earth. As seen from the Earth, the sun rotates on its axis about once every four weeks. However, it does not rotate as a solid body; the equator takes about 27 days and the polar regions take about 30 days for each rotation.

The sun has an effective blackbody[9] temperature of 5762 K[10]. Moreover, the temperature in the central interior regions is variously estimated at $8\cdot 10^{6}$ to $40\cdot 10^{6}$ K and the density at about 100 times that of water[11].

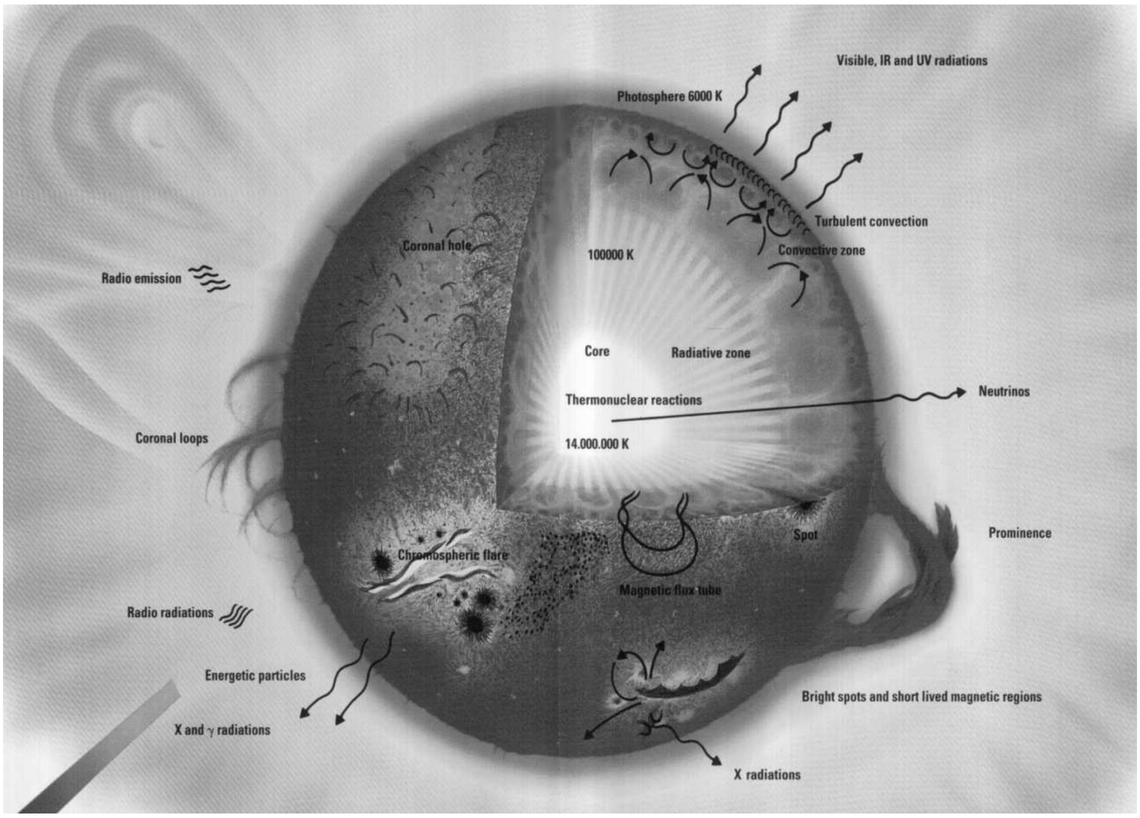

Figure 2.2.1. Nuclear reactions related with sun’s structure

(NASA - For Educators, 2011)

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[9] Blackbody: in physics, is a surface that absorbs all radiant energy falling on it. The term arises because incident visible light will be absorbed rather than reflected, and therefore the surface will appear black (Enciclopaedia Britannica, 2011).

[10] This effective blackbody temperature of 5762 K is the temperature of a blackbody radiating the same amount of energy as does the sun.

[11] Density of liquid water: 1000 kg/m^3.

In its core, the sun converts about 4,5 million tons of matter into energy every second. It can be said that it is a continuous fusion reactor retained by gravitational forces, producing neutrinos and solar radiation. Several fusion reactions have been suggested to supply the energy radiated by the sun; the one considered the most important is a process in which hydrogen (i.e., four protons) combines to form helium (i.e., one helium nucleus). Therefore, as the mass of the helium nucleus is less than that of the four protons, the mass has been lost in the reaction and is converted to energy.

This energy must be transferred out through the surface and then radiated into space by a succession of radiative and convective processes: successive emission, absorption and reradiation. The radiation in the sun's core must be in the x-ray and gamma-ray parts of the spectrum with the wavelengths of the radiation increasing as the temperature drops al larger radial distances.

It is estimated that 90% of the energy of the sun is generated in the region of 0 to 0,23R (R is the radius of the sun) called n*ucleus*, which contains 40% of mass of the sun. Meanwhile the rest is produced by the others zones as follows: at distance 0,7R from the centre, the temperature has dropped to about 130.000 K and the density has dropped to 70 kg/m^3; here convection process begin to become important and the zone from 0,7 to 1R is known as the *convective zone*; within this zone, the temperature drops about 5000 K and the density to about 10^{-5} kg/m^3. Apart from these zones, which comprise of the "solid" part of the sun, there are other zones or layers outside which are also part of the sun itself.

Starting in the surface, the outer layer of the convective zone is called the *photosphere*; its edge is sharply defined, even though it is of low density (about 10^{-4} that of air at sea level[12]). It is essentially opaque, as the gases of which it is composed are strongly ionized and able to absorb and emit a continuous spectrum of radiation[13]. The photosphere is the source of most solar radiation. Outside the photosphere there is a more or less transparent solar atmosphere, and above it there is a layer of cooler gases several hundred kilometres deep called the *reversing layer*. Outside of that is a layer referred to as the *chromosphere*, with a depth of about 10.000 km, which consist of a gaseous layer with temperatures somewhat higher than that of the photosphere and with lower density. Finally, still further out, is the *corona*, of a very low density and of a very high temperature (10^6 K). These sun layers are listed, and represented in Figure 2.2.2:

- Nucleus (0 – 0,23R)
- Medium zone (0,23 – 0,7R)
- Convective zone (0,7 - 1R)
- Photosphere
- Reversing layer
- Chromosphere
- Corona

(Duffie & Beckman, 1980)

[12] Density of air: 1,2754 kg/m^3

[13] The electromagnetic spectrum is the entire distribution of electromagnetic radiation according to frequency or wavelength (Enciclopaedia Britannica, 2011). The electromagnetic spectrum of an object is the characteristic distribution of **electromagnetic radiation** emitted or absorbed by that particular object.

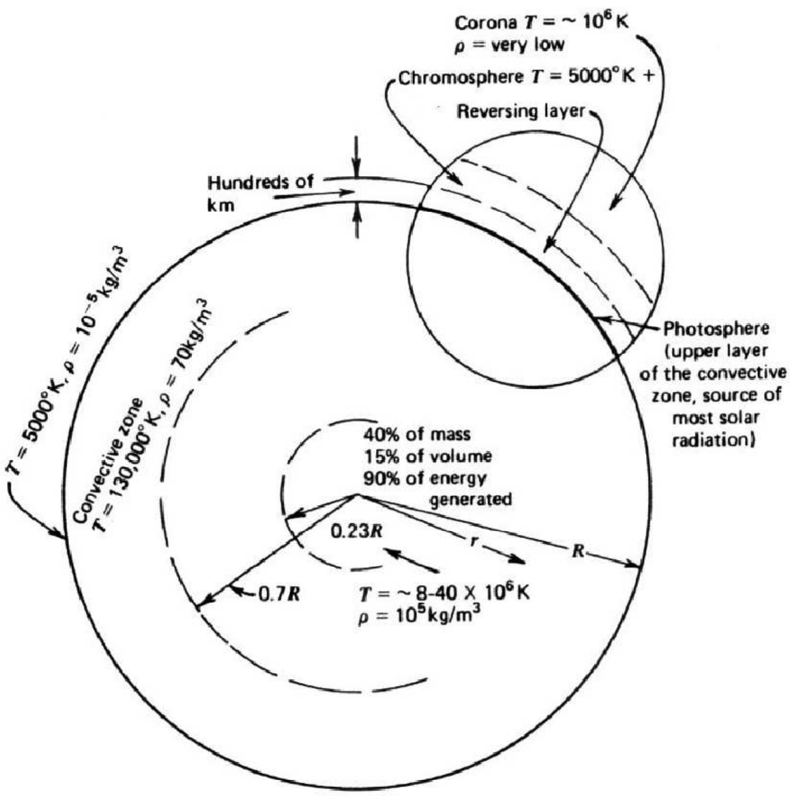


Figure 2.2.2. Schematic structure of the sun.

To summarize, this simplified picture of the sun, its physical structure, and its temperature and density gradients, will serve as a basis for appreciating that the sun does not, in fact, function as a blackbody radiator at a fixed temperature. Rather, the emitted solar radiation is the composite result of the several layers that emit and absorb radiation of various wavelengths. However, only a small amount of all this energy manages to penetrate Earth's atmosphere and is responsible for providing the light and heat that support life.

(Duffie & Beckman, 1980)

2.2.2 Direction of beam radiation

The relationships between the incoming beam solar radiation[14] and the position of the sun relative to a plane contained on the Earth's surface can be described in terms of several angles:

- Zenith Angle, θ_z. The angle subtended by a vertical line to the zenith (i.e., the point directly overhead) and the line of sight to the sun. Zenith is the "point on the celestial sphere directly above an observer on the Earth" (Enciclopaedia Britannica, 2011). So, the zenith angle is the angular distance between the zenith and the current position of the sun.
- Solar height, α_s. Angular position of the sun referred to the ground, or to the horizontal plane. Its expression is as follows:

14 Beam radiation: The solar radiation received from the sun without having been scattered by the atmosphere.

$$\alpha_s = \frac{\pi}{2} - \theta_z$$

Equation 2.2-1

- Latitude, φ. That is the angular location north or south of the equator, north being positive. The range of the latitude is -90º ≤ φ ≤ 90º. It varies during the day and depends on the season.

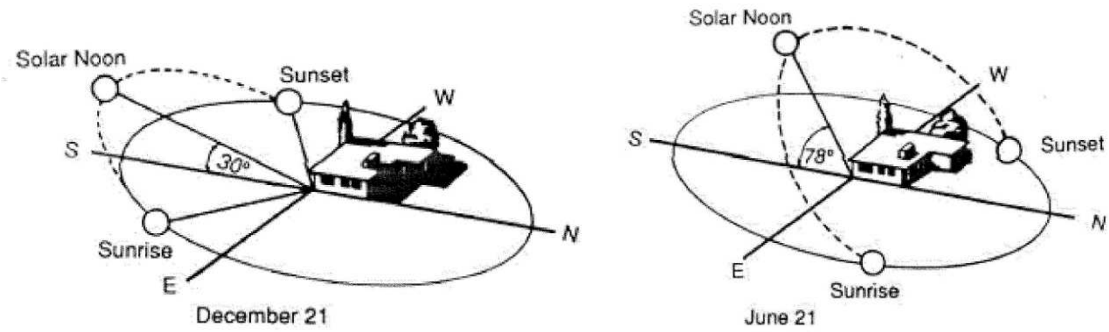


Figure 2.2.3. Latitude comparison between winter and summer solstices.

(Departamento de Ingeniería Térmica y Fluidos, 2004)

- Declination, δ. This is the angular position of the sun at solar noon with respect to the plane of the equator. In the north hemisphere this is regarded as positive and in the south as negative; it varies sinusoidally between -23,45º ≤ δ ≤ 23,45º. The declination can be found from the equation of Cooper (1969), Where n is the day of the year:

$$\delta = 23{,}45\, sin\left(360 \cdot \frac{284 + n}{365}\right)$$

Equation 2.2-2

In Figure 2.2.4. is represented the variation of the declination along year 2010.

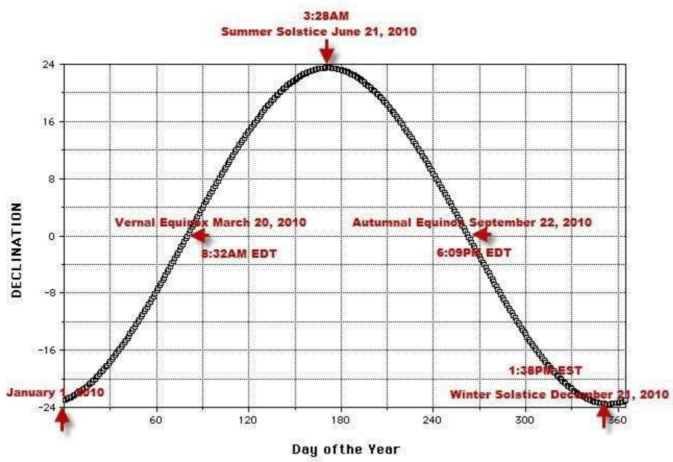


Figure 2.2.4. Sinusoidal variation of the declination during the year 2010.

(Prospectly, 2010)

The fact that the axis of the earth is tilted, leads to the existence of the seasons, as shows Figure 2.2.5.

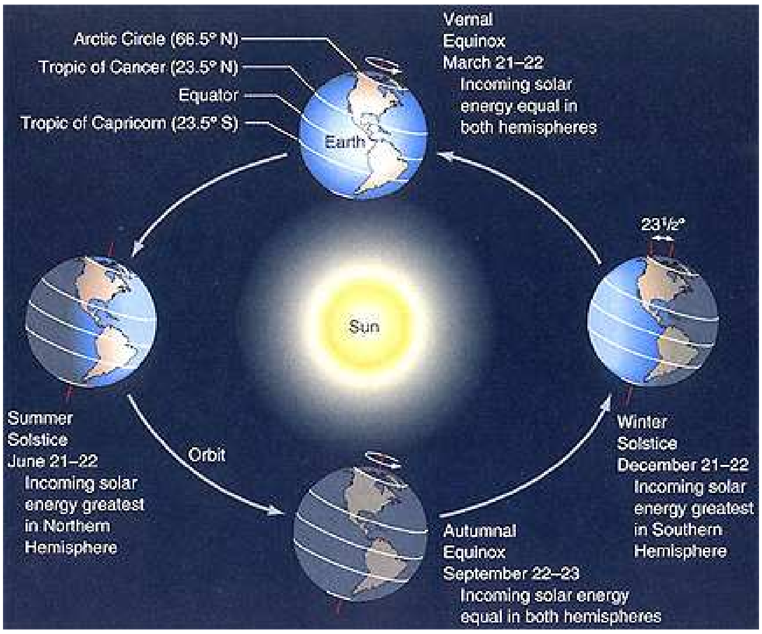


Figure 2.2.5. The Earth's seasons and declination.

(Cain, 2008)

- Hour angle, ω. This is the angular displacement of the sun east or west of the local meridian due to the rotation of the earth on its axis at 15º per hour, considering morning as negative and afternoon as positive, when the sun is at its zenith, the hour angle is nil.
- Sunset hour angle, ω_S. Angular measure when the Sun is in position of sunrise and in sunset; that also means that the zenith angle is $\theta_z = 90º$. And can be obtained with the expression:

$$\cos \omega_s = -\tan \varphi \tan \delta \rightarrow \omega_s = \cos^{-1}(-\tan \varphi \tan \delta)$$

Equation 2.2-3

It also follows that the number of daylight hours, N, is given by

$$N = \frac{2}{15} \cdot \omega_s = \frac{2}{15} \cdot \cos^{-1}(-\tan \varphi \tan \delta)$$

Equation 2.2-4

Obviously, averaged over the year, every location on earth has the same amount of hours of daylight. However, the annual distribution varies by latitude. While cities with higher latitude enjoy more hours of daylight in summer, the peak intensity remains lower due to the larger zenith angle. This variation is represented in Figure 2.2.6.

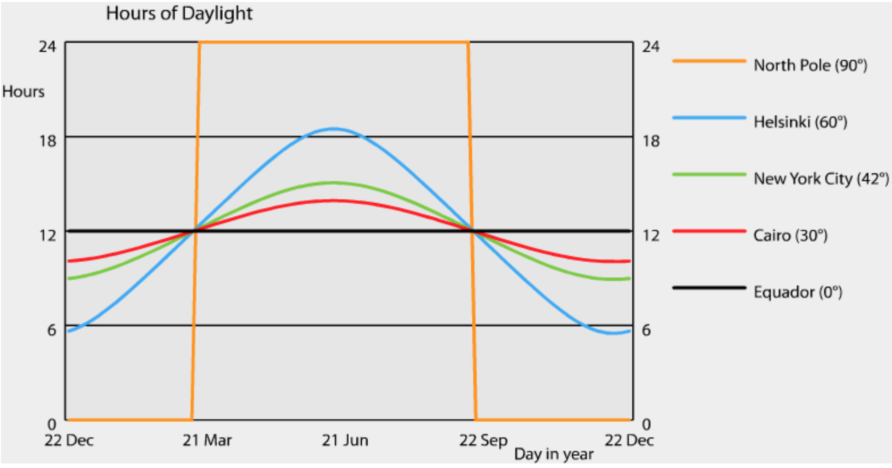


Figure 2.2.6. Number of hours of day light for different latitudes along the year. (Green Rhino Energy, 2010)

- Solar azimuth angle, γ_s. That is the angular displacement from south of the projection of the beam radiation on the horizontal plane. The angles on the west being positive, and negative on the east: $-180^o \leq \gamma_s \leq 180^o$.

As far as this thesis is concerned, it is important to know the geometric relationships of a surface (i.e. solar collector) in any particular orientation relative to Earth at any time. Thus, the angles and relationships related to the position of this surface are:

- Surface azimuth angle, γ. This is the deviation of the projection on a horizontal plane of the normal to the surface from the local meridian. As the solar azimuth angle, it varies between $-180^o \leq \gamma \leq 180^o$.
- Slope, β. This is the angle between the plane surface in question (the collector object of study) and the horizontal. Its range is $0^o \leq \beta \leq 180^o$; if $\beta > 90^o$, which means that the surface has a downward facing component.
- Angle of incidence, θ. This is the angle between the beam radiation on a surface, in any orientation, and the normal to that surface.

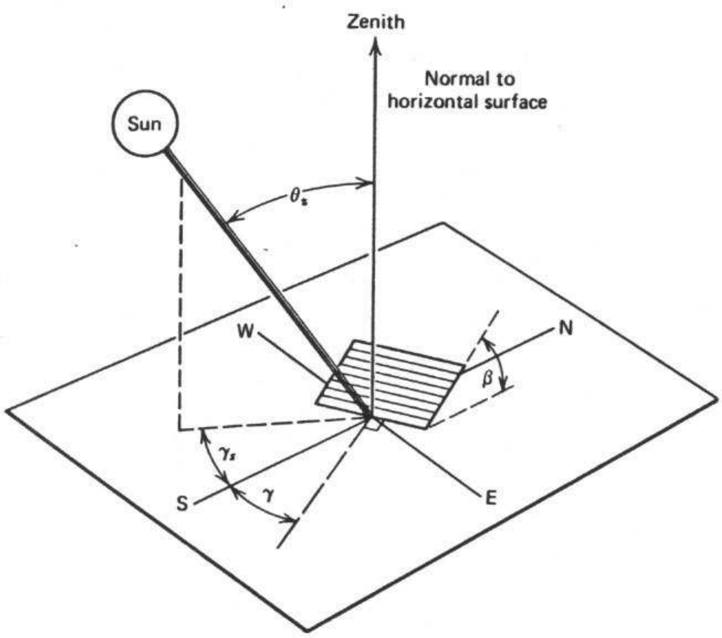


Figure 2.2.7. Positioning angles for a tilted surface.

In a spherical coordinate system, with the centre in the support of a supposed collector, and being the solar position defined by the zenith (θ_z) and azimuth (γ_s) angles, the previous geometrical relationships can be show in Figure 2.2.7.

The equation relating the angle of incidence of beam radiation, θ, and the other angles is:

$$\cos\theta = \sin\delta \sin\varphi \cos\beta - \sin\delta \cos\varphi \sin\beta \cos\gamma + \cos\delta \cos\varphi \cos\beta \cos\omega + \cos\delta \sin\varphi \sin\beta \cos\gamma \cos\omega + \cos\delta \sin\beta \sin\gamma \sin\omega$$

Equation 2.2-5

Useful relationships for the angle of incidence on surfaces sloped to the north or south can be derived from the fact that surfaces with slope β to the north, or south respectively, have the same angular relationship to beam radiation as a horizontal surface at an artificial latitude of (φ - β). Therefore, the expression for the angle of incidence in the case studied in this thesis, as Finland and Spain are situated in the northern hemisphere, is:

$$\cos\theta = \cos(\varphi - \beta)\cos\delta\cos\omega + \sin(\varphi - \beta)\sin\delta$$

Equation 2.2-6

The relationship between the latitude and the slope of a collector, which, as is in the northern hemisphere, is tilted to the south, is shown in Figure 2.2.8.

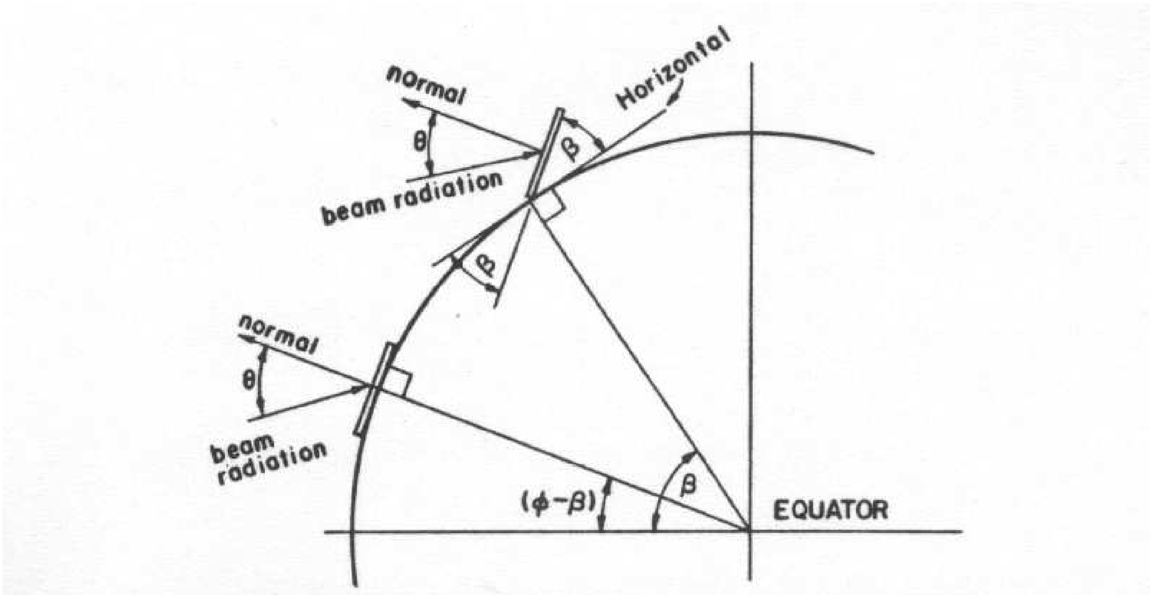


Figure 2.2.8. Section of Earth showing β, θ, φ and (φ - β) for a south-facing surface. (Duffie & Beckman, 1980)

2.2.3 Solar Radiation

2.2.3.1 Extraterrestrial radiation

For all the possible analysis that could be done about solar energy, the principal value to be known is which is the value of the extraterrestrial solar radiation, also called solar constant, G_{sc}. Its definition is “the energy from the sun, per unit time, received on a unit area of surface perpendicular to the direction of propagation of the radiation, at the earth’s mean distance from the sun, outside the atmosphere” (Duffie & Beckman, 1980). Nowadays, is accepted that its average value is 1367 W/m^2 (ACRIM, 2011).

However, the extraterrestrial radiations vary during the year for two main reasons: the variation in the radiation emitted by the sun, related to sunspot[15] activities; and the variation of the earth-sun distance, from 1,47 to 1,52 millions of kilometres.

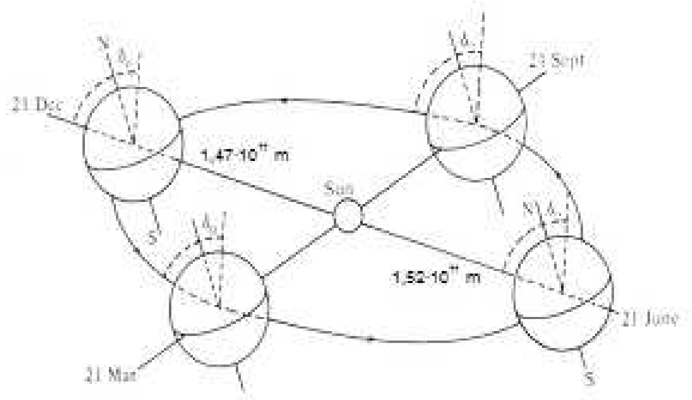


Figure 2.2.9. Earth-sun distance variations during the year.

(Departamento de Ingeniería Térmica y Fluidos, 2004)

Thus, the dependence of extraterrestrial radiation on the time of year is indicated by:

$$G_{on} = G_{sc} \cdot \left(1 + 0{,}003 \cdot cos \frac{360n}{365}\right)$$

Equation 2.2-7

Where G_{on} is the extraterrestrial radiation, measured on the plane normal to the radiation on the n^{th} day of the year.

The symbol G is used for Irradiance [W/m^2], which is the rate at which radiant energy is incident on a surface, per unit area of surface. It can be beam of diffuse radiation[16].

At any point in time, the solar radiation outside the atmosphere incident on a horizontal plane, G_o, is:

$$G_o = G_{sc} \cdot \left(1 + 0{,}003 \cdot cos \frac{360n}{365}\right) cos\, \theta_z$$

Equation 2.2-8

From Equation 2.2-5, and as for horizontal surfaces $\beta = 0$, and the angle of incidence is the zenith angle of the sun, θ_z, cos θ_z becomes

$$cos\, \theta_z = cos\, \varphi\, cos\, \delta\, cos\, \omega + sin\, \varphi\, sin\, \delta$$

Equation 2.2-9

Therefore, combining Equations 2.2-8 and 2.2-9, G_o for a horizontal surface at any time between sunrise and sunset is given by Equation 2.2-10.

$$G_o = G_{sc} \cdot \left(1 + 0{,}003 \cdot cos \frac{360n}{365}\right) cos\, \varphi\, cos\, \delta\, cos\, \omega + sin\, \varphi\, sin\, \delta$$

Equation 2.2-10

[15] Sunspot: vortex of gas on the surface of the Sun associated with strong local magnetic activity (Enciclopaedia Britannica, 2011).

[16] Diffuse Radiation: The solar radiation received from the sun after its direction has been changed by scattering by the atmosphere.

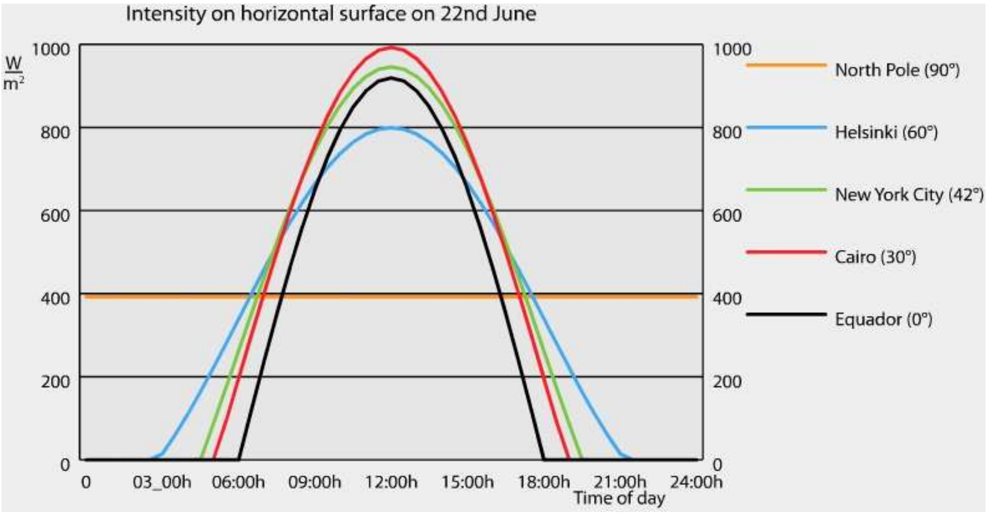


Figure 2.2.10. Irradiance during a day for different latitudes.

(Green Rhino Energy, 2010)

Figure 2.2.10 represents the irradiance on a horizontal surface during a day for different latitudes. Is important to remark that special attention must be paid to the latitudes for Helsinki, 60º, and New York, 42º, as are going to be the latitudes object of study. Helsinki for the Finnish case (even if this study is going to be placed in the City of Tampere, whose latitude is 61º) and New York as it has similar latitude as Madrid (41º), city of reference for studying Spanish situation.

Moreover, it is also necessary for calculations to know the Irradiation or Radiant Exposure, known as Insolation [J/ m^2][17]. This is the incident energy per unit area on a surface, found by integration of irradiance over a specified time, usually an hour or a day. The symbol *H* is used for insolation for a day (or other period if specified), and the symbol *I* is used for isolation for an hour. *H* and *I* can be beam, diffuse, or total and can be on surfaces at any orientation.

Hence, the integrated daily extraterrestrial radiation on a horizontal surface, H_o, is

$$H_o = \frac{24 \cdot 3600}{\pi} \cdot G_{on} \cdot \left(\cos\varphi \cos\delta \sin\omega_s + \frac{2\pi\omega_s}{360} \sin\varphi \sin\delta \right)$$

Equation 2.2-11

Figure 2.2.11 shows how the extraterrestrial irradiation varies depending on the latitude of the place where it is measured.

[17] Insolation can be also found expressed by the units [kWh/m^2]

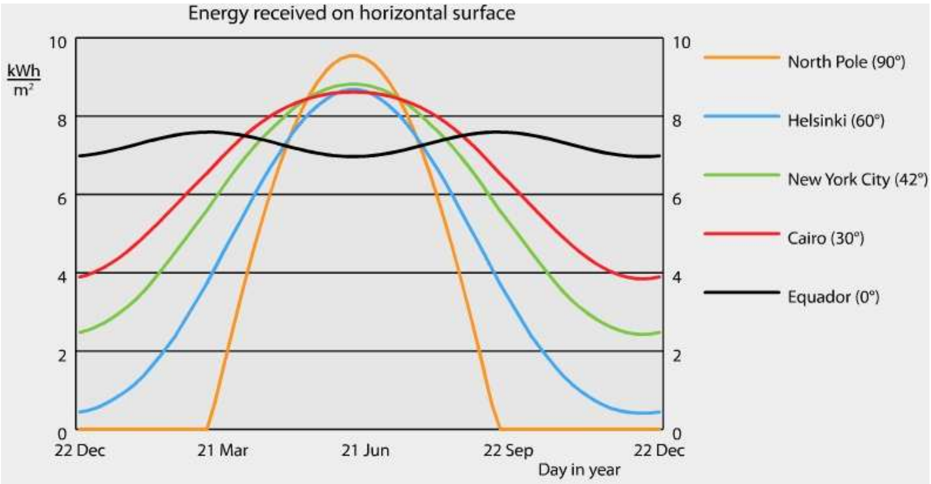


Figure 2.2.11. Annual variation of the daily extraterrestrial irradiation for different latitudes.

(Green Rhino Energy, 2010)

And for obtaining the extraterrestrial radiation on a horizontal surface for an hour period, I_o, the expression to be used is

$$I_o = \frac{12 \cdot 3600}{\pi} \cdot G_{on} \cdot \left(\cos\varphi \cos\delta \sin(\omega + 15deg) + \frac{2\pi}{360} \sin\varphi \sin\delta \right)$$

Equation 2.2-12

2.2.3.2 Solar radiation at the earth's surface

In addition to the variations explained above, it has to be taken into account that other influences exist that attenuate the radiation which reaches the surface: the atmosphere.

Once inside the atmosphere, there are two significant phenomena that also affect the beam radiation:

- *Scattering*: due to the light's interaction with air molecules, water vapour and dust.
- *Atmospheric absorption*: in the solar energy spectrum[18] due largely to O_3 (ozone) in the ultraviolet[19] and H_2O (water) and CO_2 (carbon dioxide) in bands in the infrared.

The total radiation that reaches Earth's surface is lower than extraterrestrial; its spectrum varies and not all of it has the same direction. As well as direct radiation, there is also indirect or diffuse radiation.

Figure 2.2.12 shows the spectrum of solar radiation before trespassing the atmosphere (biggest smooth graph) and the real radiation that reaches the earth's

[18] Spectrum: in optics, the arrangement according to wavelength of visible, ultraviolet, and infrared light (Enciclopaedia Britannica, 2011).

[19] Ultraviolet radiation (UV): is the portion of the electromagnetic spectrum extending from the violet, or short-wavelength, end of the visible light range to the X-ray region; it is undetectable by the human eye (Enciclopaedia Britannica, 2011).

surface, in which are marked the absorptions caused by O_3, H_2O and CO_2. Also in this graph is possible to see clearly the range of visible light[20].

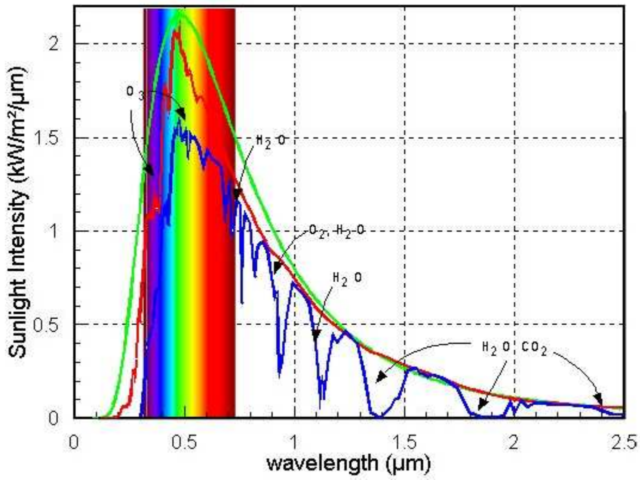


Figure 2.2.12. Comparison of solar radiation outside the Earth's atmosphere with the amount of solar radiation reaching Earth itself

(Hornsberg & Bowden, 2010)

The spectral distribution of total solar radiation[21] depends also on the spectral distribution of the diffuse radiation. Total solar radiation is sometimes used to indicate quantities integrated over all wavelengths of the solar spectrum.

(Duffie & Beckman, 1980)

To express the amount of intensity that is lost through *absorption*, the clearness index, K, is defined as the ratio between the observed (global) daily irradiance on earth, H_g, and the daily radiation H_o just outside the atmosphere:

$$K = \frac{H_g}{H_o}$$

Equation 2.2-13

The actual values for K have to be measured. The typical values are:

- For clear sky at sea level: $0,6 < K < 0,8$
- For cloudy weather: $0,1 < K < 0,3$

The clearness index is usually either daily or hourly to average out short-term fluctuations. It is assumed that clouds are uniformly distributed over the sky. Drifting clouds are not considered in this technique.

Around 18% of the extraterrestrial radiation is absorbed or reflected back. Higher latitudes experience lower values, as the path through the atmosphere under a larger zenith angle is much longer.

---

[20] Visible light: is the portion of the electromagnetic spectrum visible to the human eye. It ranges from the red end to the violet end of the spectrum, with wavelengths from 700 to 400 nanometers (Enciclopaedia Britannica, 2011).

[21] Total Solar Radiation: The sum of the beam and the diffuse radiation on a surface.

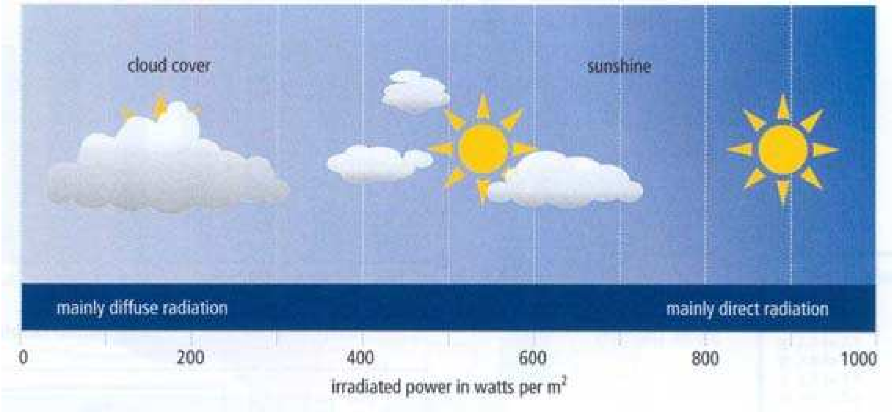


Figure 2.2.13. Global solar irradiance with different sky conditions.

(James, 2005)

About *diffusion*, diffuse light is a result of absorption and scattering, which approaches the horizontal surface from almost any angle. It can therefore not be focused or concentrated.

The global hourly irradiance on a surface can be expressed as the sum of direct, or beam, and diffuse radiation:

$$H_g = H_{Beam} + H_{Diffuse}$$

Equation 2.2-14

Similar to the clearness index, the diffusion index, K_D, is defined in Equation 2.2-15. As a result, the beam fraction is $1 - K_{D.}$

$$K_D = \frac{H_{Diffuse}}{H_g}$$

Equation 2.2-15

Figure 2.2.14 shows the relationship between the beam fraction and the clearness, index for latitudes around 50°N. Also, it represents that clear skies cause less diffusion. However, where there are clouds, the ratio of diffuse light can be in excess of 75%. Any devices that concentrate light onto a single point rely on a high proportion of direct beam and are therefore not suitable in locations with high diffusion index.

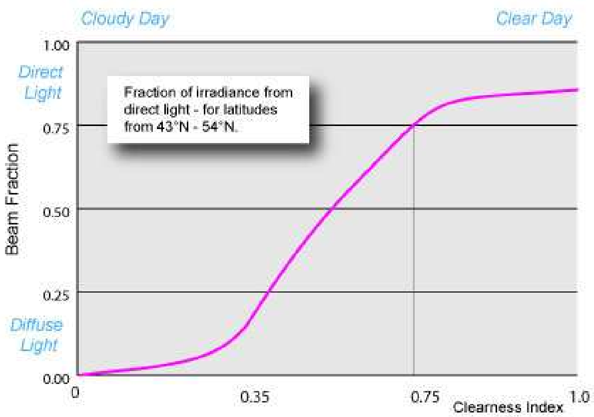


Figure 2.2.14. Fraction of irradiance from direct light for latitudes around 50º.

(Green Rhino Energy, 2010)

Besides the phenomena that affect the radiation and the thickness of the atmosphere, it is also important to notice that the Earth's curvature matters. This means that the amount of air that the radiation has to go through, before reaching the ground, depends on the Zenith Angle, θ_z.

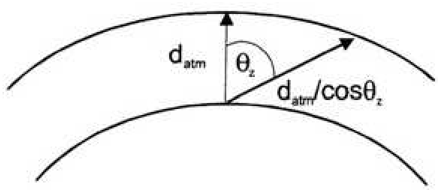


Figure 2.2.15. Dependence of atmospheric thickness on the zenith angle.

(Departamento de Ingeniería Térmica y Fluidos, 2004)

Equation 2.2-16 represents the air mass (*m*), which is the ratio of the optical thickness of the atmosphere through which beam radiation passes to the optical thickness if the sun were at its zenith. Thus, at sea level, m = 1 when the sun is at the zenith, and m = 2 for a zenith angle θ_z = 60º. For zenith angles from 0º to 70º at sea level, and being d_{atm} the atmospheric thickness, the air mass is:

$$m = \frac{{d_{atm}}/{\cos\theta_z}}{d_{atm}} = (\cos\theta_z)^{-1}$$

Equation 2.2-16

For higher zenith angles, the effect of the earth's curvature becomes significant and must be taken into account.

(Duffie & Beckman, 1980)

Figure 2.2.16 represents the incidence of sun light on the Earth, and the effects of the latitude and the atmosphere on the radiation received in the horizontal surface, i.e. collector. Where in the Figure appears "AM", this means Air Mass (m).

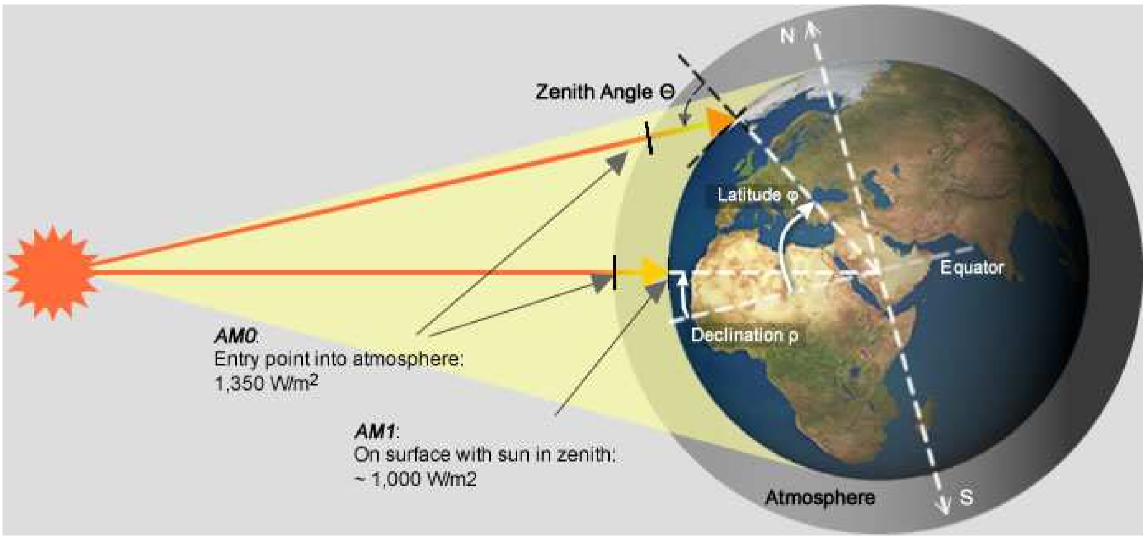


Figure 2.2.16. Effect of latitude variations and the atmosphere in energy received in Earth's surface.

(Green Rhino Energy, 2010)

2.2.4 Solar Radiation on tilted surface

As sunlight is smoothly distributed over whole areas, a mere figure for intensity is never sufficient without knowledge of the orientation of the surface in question. Typically, the orientation of a surface is described by the zenith angle, the angle between the sunbeam and the normal of the area. If the surface area is not perpendicular to the sunbeam (i.e. zenith angle is not zero), a larger area is required to catch the same flow as the cross section of the sunbeam; therefore the intensity in tilted surfaces in higher for the same sun flow. These areas are represented in Figure 2.2.17.

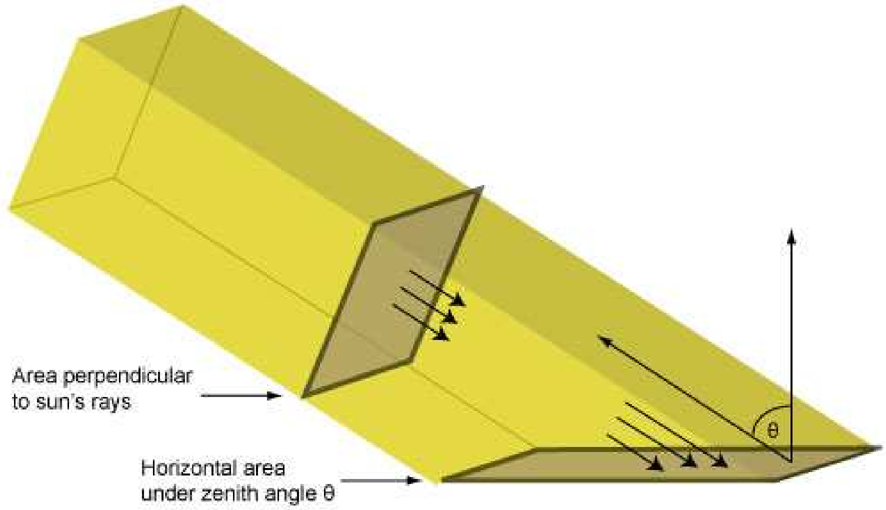


Figure 2.2.17. Incidence of sun's rays in horizontal and tilted surfaces.

If I_b denotes the irradiation on a surface with the sun in its zenith, the irradiation on an area where the sun is observed under the zenith angle θ_z (in the figure is expressed as plain θ), $I_{b,n}$, which means on an horizontal surface, the irradiation is reduced to

$$I_{b,n} = I_b\, cos(\theta_z)$$

Equation 2.2-17

(Green Rhino Energy, 2010)

Thus, the expression of the irradiation on a tilted surface, $I_{b,T}$, expressed as a function of the incidence angle θ, nor the zenith angle θ_z, is

$$I_{b,T} = I_b\, cos(\theta)$$

Equation 2.2-18

Where the incident angle of sun beam radiation over the tilted surface, θ, is obtained as follows

$$\theta = \theta_z - \beta$$

Equation 2.2-19

For better understanding, Figure 2.2.18 shows those angles and the named irradiations.

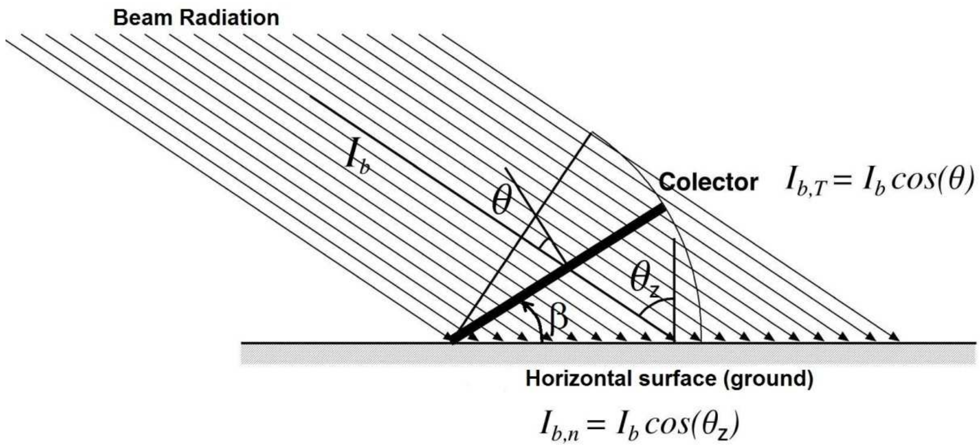


Figure 2.2.18. Irradiation on a tilted surface.

2.2.4.1 Optimum Surface Orientation

After all these statements can be derived that, in order to obtain the maximum quantity of solar radiation per surface unit, is needed to tilt the collector till the solar beam radiation reaches the surface perpendicularly.

In the northern hemisphere, if the latitude φ, is bigger than the declination δ, the collector must be tilted heading south. Vice versa for the southern hemisphere.

The optimum slope β of the collector, β_{opt}, is the difference between the latitude and declination, and consequently varies along the year. The expression of this optimum tilting depending on *n*, which is the day of the year, is:

$$\beta_{optimum}(n) = \varphi - \delta(n)$$

Equation 2.2-20

(Departamento de Ingeniería Térmica y Fluidos, 2004)

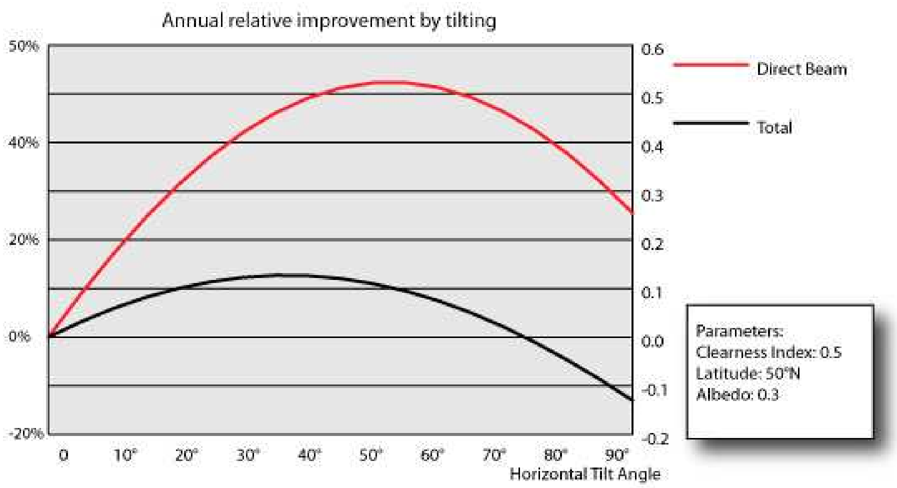


Figure 2.2.19. Annual insolation improvement by tilting compared to horizontal situation.

There are different ways of taking care of this seasonal variation that is needed to face for obtaining the maximum irradiance on the tilted surface.

Tracking

In order to maximize the direct beam insolation on a surface, it is possible to rotate the surface around two axes, namely the tilt and the azimuth angle, which requires two motors. Tracking collectors can be one-axis tracking or two-axis tracking.

Figure 2.2.20. Two-axis tracking collector.

(Allbiz)

Typically, the marginal energy gains from tracing the azimuth angle are low. Hence, the second best option is to keep the slope flexible, but facing due south.

Fixed Tilt

In case there is no possibility to move the surface at all, it is considered south direction as optimal orientation, and the optimal tilt angle, β_{opt}, for receiving the maximum amount of direct beam radiation, depends on the period of use of the solar installation:

- Constant annual Consumption: tilting must be equal to the latitude, $\beta = \varphi$.
- Preferential winter consumption: tilting should be the latitude increased in 10°, $\beta = \varphi + 10^o$.
- Preferential summer consumption: tilting should be the latitude decreased in 10°, $\beta = \varphi - 10^o$.

(IDAE, 2009)

However, as tilting the surface up causes the diffuse light portion to decrease, another consideration must be taken for humid climates: decrease the tilting by setting 10 – 25% less than the latitude. In Germany, for instance, at 48°N, a tilt angle of 30° would be optimal, whereas in Spain, it could be up to 40°.

Seasonal Tilt

In regions where most of the irradiance occurs in summer, it may be beneficial to adjust the tilt angle for winter and summer. For example, in Germany, 75% of solar irradiance is experienced from April to September. The optimal angle for the summer would be 27° and for winter 50°, rather than 30° if the modules couldn't be tilted at all. However, the case in Spain is dissimilar as seasonal differences are less pronounced (summer accounts for 60%), making a seasonal tilt less critical. In Finnish case, it should be done as in Germany.

(Green Rhino Energy, 2010)

3A Sun tracking system

A new sun-tracking concept was proposed last year (accepted on the 3rd of December 2010) in Yunnan Normal University, Kunming 650500, PR China; by Yi Ma, Guihua Li and Runsheng Tang.

The optical performance of solar panels with such sun-tracking system was theoretically investigated based on the developed mathematical method and monthly horizontal radiation. The mechanism of the proposed sun-tracking technique is that the azimuth angle of solar panels is daily adjusted three times at three fixed positions: eastward, southward and westward in the morning, noon, and afternoon, respectively, by rotating solar panels about the vertical axis (3A sun-tracking, in short).

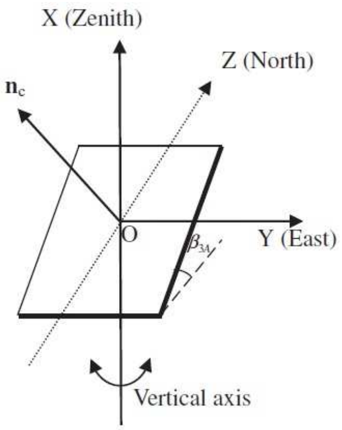


Figure 2.2.21. Geometry of three azimuth angles tracked solar panels.

The analysis indicated that the tilt-angle of solar panels, β_{3A}, the azimuth angle of solar panels in the morning and afternoon from due south, φ_a, and the solar hour angle when the azimuth angle adjustment was made in the morning and afternoon, ω_a, were three key parameters affecting the optical performance of such tracked solar panels.

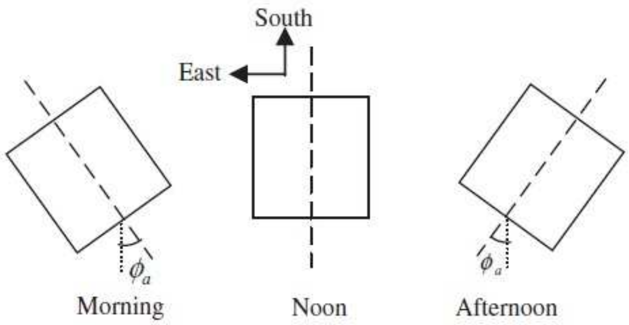


Figure 2.2.22. Three orientations of 3A tracked solar panels (top view).

Calculation results showed that, for 3A tracked solar panels with a yearly fixed tilt-angle, the maximum annual collectible radiation was above 92% of that on a solar panel with full 2-axis sun-tracking; whereas for those with the tilt-angle being seasonally adjusted, it was above 95%. Results also showed that yearly or seasonally optimal values of β_{3A}, φ_a and ω_a for maximizing annual solar gain were related to site latitudes, and empirical correlations for a quick estimation of optimal values of these parameters were proposed based on climatic data of 32 sites in China.

(Ma, Li, & Tang, 2011)

2.2.4.2 Total radiation on tilted surfaces

According to Liu and Jordan's model (1963), which is an improvement from the isotropic model, the global radiation can be decomposed in three components: beam radiation, diffuse solar radiation, and solar radiation diffusely reflected from the ground.

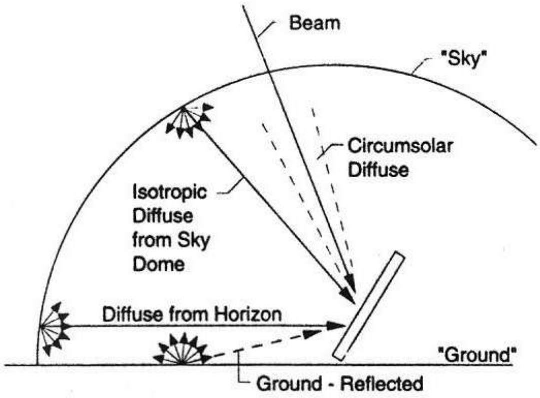


Figure 2.2.23. Components of total radiation on a tilted surface.

The complexity of deducing how much radiation belongs to each component is that flat-plate solar collectors absorb both beam and diffuse components of solar radiation; and solar radiation data is usually registered for a horizontal surface, without distinguishing between beam and diffuse components.

Consequently, for using horizontal total radiation data to estimate radiation on the tilted plane of a collector of fixed orientation, it is necessary to know the geometric factor R_b, which is the ratio of beam radiation on the tilted surface, $G_{b,T}$, to that on a horizontal surface at any time, G_b. This ratio is given by

$$R_b = \frac{G_{b,T}}{G_b} = \frac{G_{bn} \cos\theta}{G_{bn} \cos\theta_z} = \frac{\cos\theta}{\cos\theta_z}$$

Equation 2.2-21

Where $\cos\theta$ and $\cos\theta_z$ are the incidence and zenith angles respectively, and can be determined from Equations 2.2-6 and 2.2-9.

As the global radiation, I_T, is the sum of the three radiation components:

$$I_T = I_{b,T} + I_{d,T} + I_{r,T}$$

Equation 2.2-22

Each component is defined as:

- Beam radiation, $I_{b,T}$.

Represents the direct part of solar radiation.

$$I_{b,T} = I_b R_b$$

Equation 2.2-23

- Diffuse radiation, $I_{d,T}$.

Assuming an isotropic distribution of the diffuse radiation over the hemisphere, the diffuse part is only dependent on the horizontal tilt angle β and the diffuse radiation of the horizontal surface. The correction for the diffuse component depend on the distribution of diffuse radiation over the sky, which depends on the type, extent and location of clouds, and also on the amounts and spatial distribution of other atmospheric components that scatter solar radiation. Then, if a surface tilted at slope β from the horizontal has a view factor to the sky given by $\left(\frac{1+\cos\beta}{2}\right)$, the diffuse radiation can be expressed as

$$I_{d,T} = I_d \left(\frac{1+\cos\beta}{2}\right)$$

Equation 2.2-24

- Reflected radiation, $I_{r,T}$.

Some solar radiation may be reflected from the ground to the surface. The energy of the reflected light is dependent on the ground's ability to reflect, a property which is expressed by the albedo factor ρ. The albedo, or reflectance, varies from 0,15 to 0,85, as can be seen in Table 2.2.1. (Green Rhino Energy, 2010)

Table 2.2.1. Albedo range.

Albedo ρ	
Asphalt	0,15
Naked Ground	0,17
Lawn	0,21
Untilted Field	0,26
Weather-beaten concrete	0,30
Old snow	0,58
Fresh snow	0,85

The surface has a view factor to the ground of $\left(\frac{1-\cos\beta}{2}\right)$, and if those surroundings have reflectance of ρ for the total solar radiation, the reflected radiation from the surroundings on the surface from the solar radiation is

$$I_{r,T} = (I_b + I_d)\rho\left(\frac{1-\cos\beta}{2}\right)$$

Equation 2.2-25

Subsequently, the total solar radiation on the tilted surface for an hour is, dependant by the radiation on a horizontal surface is:

$$I_T = I_b R_b + I_d\left(\frac{1+\cos\beta}{2}\right) + (I_b + I_d)\rho\left(\frac{1-\cos\beta}{2}\right)$$

Equation 2.2-26

(Duffie & Beckman, 1980)

It can be shown with the help of the above formulas that tilting up a surface can increase the irradiance incident. The actual amount depends on numerous factors such as latitude, day in the year, albedo and clearness index as well as both the tilting angle and the surface azimuth.

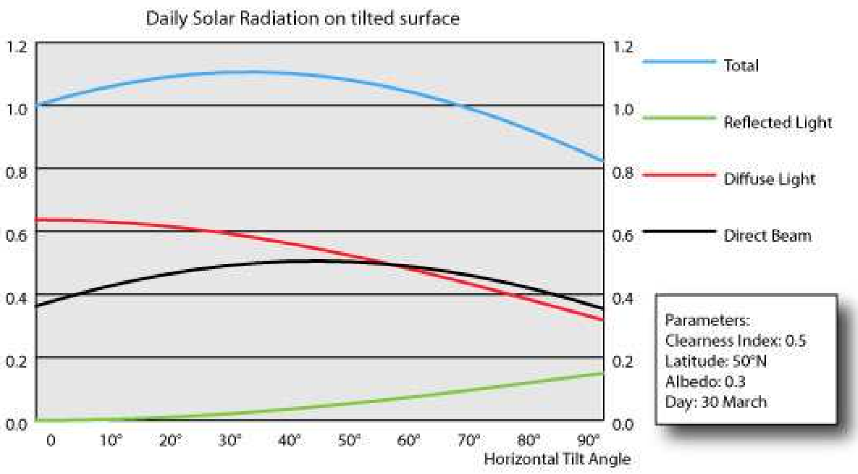


Figure 2.2.24. Irradiation components.

In Figure 2.2.24 are plotted the irradiation components relative to the global irradiation on a horizontal surface facing due south on 20th March at 50°N with an albedo of 30% on a reasonably clear day, clearness index 0,5. Under these circumstances, the optimal tilt angle would be around 40°. This can be deduced by looking at the maximum of the curve “total” (the highest curve) and its position at the horizontal axis of the graph, which refers to the horizontal tilt angle.

Intuitively, the tilting effect is more pronounced for higher latitudes, as it happens to one of the cases of this thesis: Finland.

(Green Rhino Energy, 2010)

2.2.5 Radiation losses due to collector arrangement

There are two main losses that are needed to be taken into account before dimensioning and calculating any solar installation.

2.2.5.1 Losses due to orientation and tilting

To calculate these losses, it will be necessary to know about the collector: the value of the tilting angle, β, which indicates tilting, and its azimuth angle, γ, which denotes orientation. Figure 2.2.25 shows a short reminder of these angles.

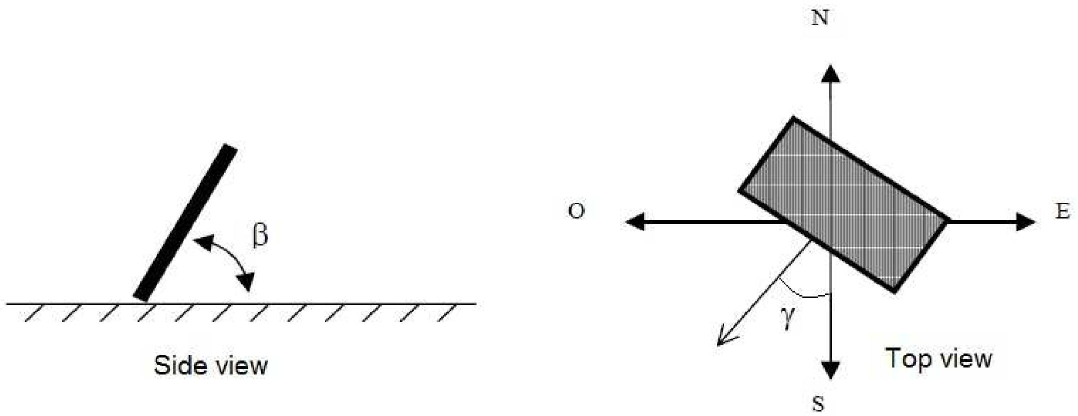


Figure 2.2.25. Orientation and tilting angle of a collector.

Once these values are known, the calculation for tilting limits is as follows:

First, is necessary to decide which the maximum acceptable losses are. For example, in Spanish solar energy regulation DB HE-4, the limits for the losses are show in Table 2.2.2 and depend on the type of installation that is going to be dimensioned; if it is going to be a general case, collector superposition[22] or architectonic integration[23].

[22] Collector superposition: the collectors are placed along the building’s shape, without double functionality, as in architectonic integration (CTE, 2009).

[23] Architectonic integration: collectors involve a double function, energetic and architectonic; further, they substitute conventional constructive elements or are themselves part of architectural composition (CTE, 2009).

Table 2.2.2. Limit energy losses.

Case	Orientation and tilting	Shadows	Total
General	10%	10%	15%
Superposition	20%	15%	30%
Architectonic integration	40%	20%	50%

Then, the acceptable tilting limits will be defined using Figure 2.2.26, where is represented the maximum percentage of available energy depending on the collector disposition, for a latitude of $\varphi = 41^o$.

The tilting limits are the intersections between the curve that defines the value of the maximum available energy (that is the opposite percentage of the limit energy losses listed on Table 2.2.2), and the azimuth line. The higher value for β correspond the maximum tilting (β_{max}) and the lower is the minimum tilting (β_{min}).

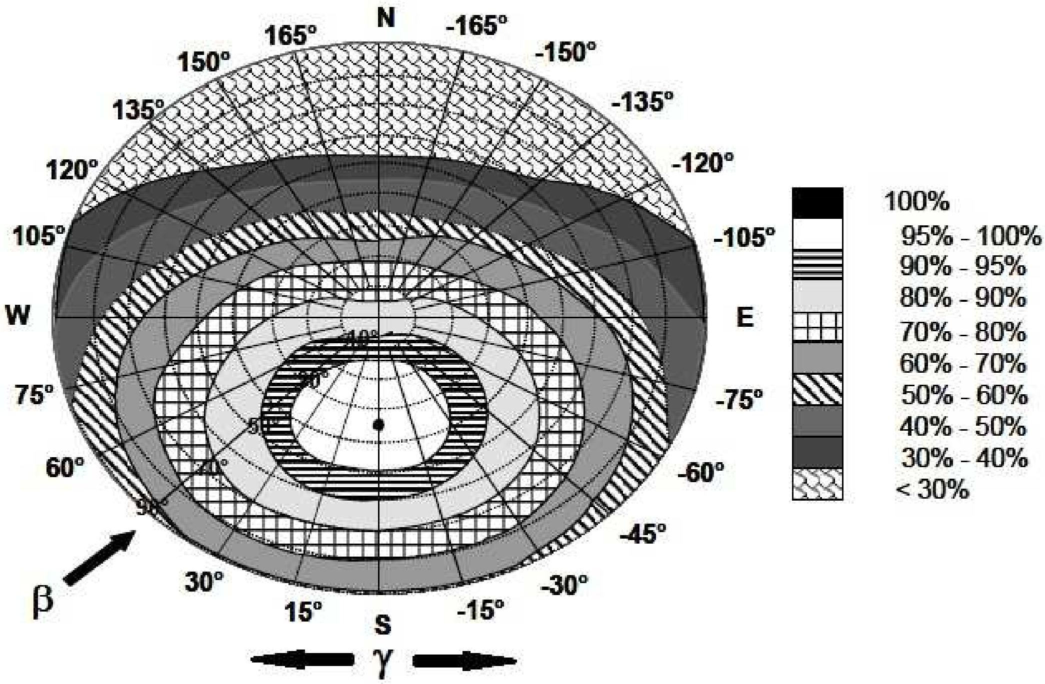


Figure 2.2.26. Percentage of available energy, taking into account the losses due to orientation and tilting, for the case of latitude: $\varphi = 41^o$.

In the case that there is no possible intersection, it implies that the losses are higher that the acceptable, consequently, the installation is outer limits. Otherwise, these values should be corrected for the real latitude where the installation will be placed, φ_r. These corrections are:

- Maximum tilting: $\beta_{max} = \beta\ (\varphi = 41^o) - (41^o - \varphi_r)$
- Minimum tilting: $\beta_{min} = \beta\ (\varphi = 41^o) - (41^o - \varphi_r)$

If it is obtained a negative angle, that means that the minimum theoretic tilting is $\beta_{min} = 0^o$.

2.2.5.2 Losses due to shadows

These kind of solar radiation losses over a surface are caused by the surrounding shadows and, as orientation losses, are expressed as the percentage of solar radiation which reaches the surface if there was no shadow.

For calculate them, the procedure is to compare the profile of obstacles which affect the collecting surface with the sun's path diagram. An example of this diagram is shown in Figure 2.2.27, valid for the Iberian Peninsula.

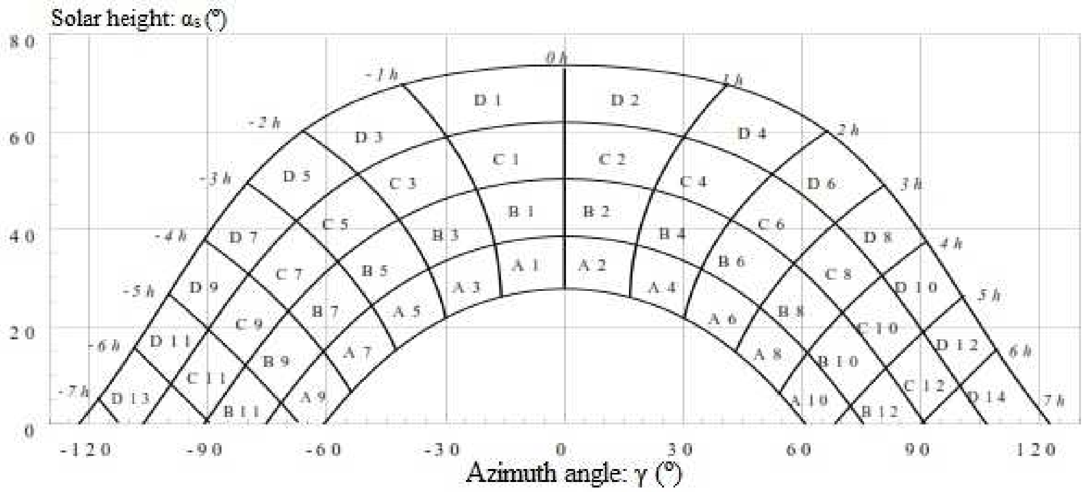


Figure 2.2.27. Sun's path diagram along the year.

It is usually divided in portions, delimited by the solar heights, α_s, and identified by a letter and a number (A1, A2,... D14). Each portion represent the sun's path during a specific period of time, therefore, it has a particular contribution to the annual global solar irradiation over the surface object of study. Hence, the fact that an obstacle covers one of the portions implies that an amount of radiation is lost, particularly the one which is intercepted by the obstacle.

In the first place, the location of the main obstacles, their azimuth and height coordinates, are needed to be calculated. Then, these coordinates should be represented over the sun's path diagram. Next, for obtaining the numerical data, a reference table should be selected; choosing the one whose situation is more alike than the one that is going to be studied. These tables vary depending on the tilting angle, β, and the azimuth angle, γ; and are listed in Appendix II: Reference tables for shadow losses. The number in each cell indicates the percentage of solar global radiation that would be lost if the corresponding portion would be intercepted by an obstacle.

The comparison between the profile of obstacles with the sun's path diagram allow obtaining the shadow losses of the solar global radiation over the surface during the year. Therefore, all the contributions of the portions that are total or partially covered by the obstacle's profile should be summed. In the case of partial covering, a filling factor[24] must be used; a numeric value must be chosen close to the values: 0,25; 0,50; 0,75 or 1.

(CTE, 2009)

And last, but not least, it has to be taken into account the distance between collectors to avoid shadows between them. Figure 2.1.28 represents the geometric coefficients.

[24] Filling factor: is the ratio relating the covered fraction of the portion and its totality.

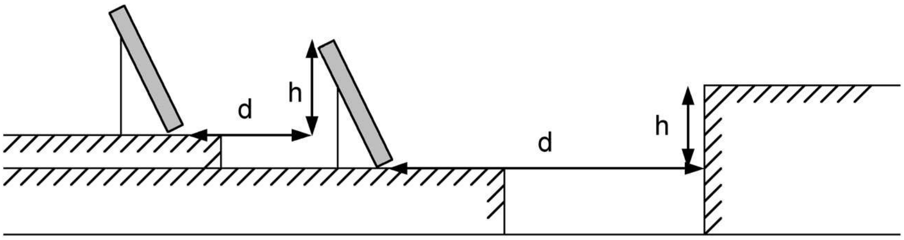


Figure 2.2.28. Distance between collector and possible obstacles.

The minimum distance between collectors, *d*, measured over the horizontal, between a row of collectors and an obstacle of height, *h*, which could produce shadows over the installation, must guarantee a minimum of 4 hours of sun light around the winter's solstice midday (21st December). Then, this minimum distance between the collectors and/or obstacles is expressed as follows

$$d = \frac{h}{tan(61º - \varphi)} = h \cdot k$$

Equation 2.2-27

Where k is a dimensionless coefficient dependant on the latitude, φ.

$$k = \frac{1}{tan(61º - \varphi)}$$

Equation 2.2-28

Table 2.2.3 shows significant values of this dimensionless coefficient for latitudes from diverse areas or cities of the countries object of study.

Table 2.2.3. Values of k for different latitudes.

Country	City/Area	Latitude ϕ [º]	k
Spain	Canary Islands	28	-0,013
	Sevilla	37	-0,468
	Madrid	40	-0,655
	Barcelona	41	0,447
Finland	Helsinki	60	0,642
	Tampere	61	1

The distance between the rear part of a row and the beginning of the next one must not be lower than the obtained with Equation 2.2-27, considering h as the height difference between the highest part of a row and the lowest part of the next one, doing the measures according to the plane which contains the collector's bases.
(IDAE, 2009)

2.3 Solar technologies

There are many ways of using the solar energy, from biomass to photovoltaic cells. And they can be distinguished by the technologies that are used to obtain energy.

In a broad sense, most energy that individuals use is some form of solar energy. Other renewable energy sources, such as wind, hydropower, and wood, are indirectly connected to solar energy by using the atmosphere, oceans, and forests as solar collectors. Even exhaustible fossil fuels (i.e. oil, coal, and natural gas) are solar energy that was originally captured by plants and concentrated by geological processes into forms with high energy densities per unit of weight and volume.

Another indication of the abundance of solar energy is, rather ironically, the threat of climate change itself. The increases in the atmospheric concentrations of well-mixed greenhouse gases from the pre-industrial to present time result mainly from the combustion of fossil fuels for energy purposes. They cause a marginal increase in the Earth and atmosphere's capacity to trap the sunrays' radiative energy, acting as a gigantic solar collector, called the radiative forcing of climate and estimated to be 2,43 Wm^{-2} ± 10%, which compares to the averaged continuous amount of solar energy on Earth of about 235 Wm^{-2}. This suggests that solar energy has the potential to help solve the problem it creates.

Indeed, the prediction of climate change and, eventually, fossil fuel depletion, generate a growing interest in renewable energies in general, solar energy in particular. The benefits of renewable energy systems were clearly defined in a political declaration agreed to by government representatives of 154 nations at the international *Renewables 2004* conference held in Bonn, June 2004, as a follow-up to the 2001 World Summit Sustainable Development, Johannesburg.

In one hand, the benefits outlined include energy supply security, equity and development, improved health, overcoming peak oil price fluctuations, provision of clean water, close association with energy efficiency measures, climate change mitigation, and the common belief that *"there will be no need for war over solar energy"*.

And in the other hand, the drawbacks are well known: the solar radiation reaching the earth is very dilute (only about 1 kWh per square meter), intermittent (available only during day time), and unequally distributed over the surface of the earth (mostly between 30° north and 30° south latitude).

Various technologies, however, can be used to overcome the difficulties in making sunlight a usable form of energy for all purposes. For instance, solar *thermal* energy designate all technologies that collect solar rays and transform their energy into usable heat, either for directly satisfying heating needs (i.e. notably space heating, water heating and space cooling) or for producing electricity and fuels. This last technology includes concentrating solar power technologies, and other concepts such as solar updraft towers and ocean thermal energy.

In more common usage, solar energy refers to the two primary ways in which people control and directly use solar energy by means of manufactured collectors: heating and generating electricity.

2.3.1 Solar heat

At present, solar heating provides by far the largest solar contribution to energy needs. The main technologies belong to either *passive* or *active* solar energy forms. Both approaches use glass to trap heat, as in a greenhouse.

2.3.1.1 Passive heating systems

Passive solar energy relates to the design of buildings collecting and transforming solar energy used for passive heating, day lighting and natural ventilation.

It is usually considered, from the demand side, as part of energy savings potential rather than from the supply side. Through a combination of a high-performance thermal envelope, efficient systems and devices, and full exploitation of the opportunities for passive solar energy, 50 to 75% of the energy needs of buildings as constructed under normal practice can be either eliminated or satisfied through passive solar means. But of course, it strongly depends on the climate.

Passive design uses no moving parts or fluids; rather, it involves incorporating features into the design of a building to take advantage of the natural solar radiation available. Such features include large windows facing south, heat absorbent material, such as brick or tile in floors and walls, and orienting a building on its site so as to maximize sun exposure.

Letting the sun heat buildings in winter, and letting daylight enter them to displace electric lighting, are the least cost solar energy forms.

2.3.1.2 Active heating systems

Active solar energy works at small scale; low temperature solar thermal systems can supply heat for domestic hot water (DHW)[25] and space heating purposes, active solar cooling, heat pumps, desalinisation and industrial high temperature heat. The main collector technologies include unglazed, glazed flat plate and evacuated tubes.

This systems use water or another liquid piped through collector units. The most common type of collector is a roof mounted flat plate design, consisting of an insulated glass-covered box painted black to maximize heat absorption. The water circulates in a loop between the collectors, where it is heated, and a tank, where it is stored until needed for either domestic uses or space heating.

2.3.2 Solar power

There are two technologies for converting solar energy to electricity.

2.3.2.1 Concentrating solar power

Concentrating solar power technologies (CSP) provide all solar thermal electricity today, and about half of the world's total solar electricity. They hold the greatest promises for the future for producing electricity.

These thermal power plants only use direct sunlight; by means of mirrors they gather the solar radiation and concentrate it several times to reach higher energy densities and thus higher temperatures when the light is absorbed by some material surface. Hence, heat is used to operate a conventional power cycle, for example through a steam or gas turbine or a Stirling engine[26], which drives a generator. These two basic features have two important consequences.

[25] Domestic Hot Water (DHW): potable water heated for uses other than space heating. It is used for showering, cleaning, laundry, etc.

[26] Stirling engine: is an external combustion reciprocating engine having an enclosed working fluid that is alternately compressed and expanded to operate a piston, thus converting heat from a variety of sources into mechanical energy. A Stirling engine can use any type of fuel as well as solar energy and heat from the waters of a hot spring. The engine was invented in 1816 by a Scottish minister, Robert Stirling, before the gasoline and diesel engines appeared (The Columbia Encyclopedia, Sixth Edition, 2008).

First, CSP are best suited in areas with high direct solar radiation; and these areas are widespread, but not universally found over the globe. The world potential seems, however, very important, as electricity demand is rapidly growing in most of these populated areas.

Second, because it uses a thermal phase, CSP technologies can easily make power production firm and even dispatchable, either by storing the heat in various forms, or by backing its production by some fossil fuel burning; in both cases using the same steam generators, turbines and generators.

CSP's concentrating collectors can be parabolic troughs or dishes, or a system of mirrors that are spread over a wide area and that focus sunlight on a receiver at the top of a tower in what is called a power tower or central receiver system; as can be seen in Figure 2.3.1.

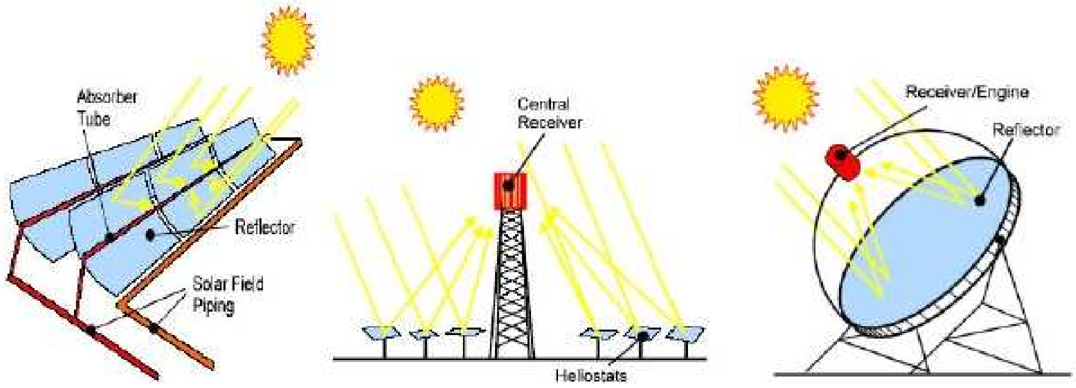


Figure 2.3.1. CSP's concentrating collectors: troughs, towers and dishes.

A fluid circulates through a receiver unit at the parabola's focal point, where it is boiled. The resulting steam drives a generator as in a conventional power plant. Unlike solar heating systems, which are installed at the point of energy consumption, CSP plants are typically large, central-station generating facilities.

2.3.2.2 Photovoltaic cells

The other solar electric technology is photovoltaic cells. These cells are made of a semiconducting material, such as silicon, that releases electrons when struck by light. Cells are typically combined into modules, which in turn are assembled into larger arrays. Arrays can be sized for residential, industrial, or electric-utility use.

The most commonly used material is crystalline silicon, but research since the 1970s has produced advances in such newer designs as thin-film cells using noncrystalline (amorphous) silicon, cadmium telluride, and other materials.

2.3.3 Solar hydrogen and other fuels

Solar hydrogen and fuels can be produced by a variety of means. Photovoltaic cells in association with electrolysis are often quoted but may not be the most cost-effective. Indeed, warm waters require less power for being electrolysed and integrated systems are being developed associating photovoltaic cells, solar water heating (SWH) and electrolysers.

A mid-term goal may be the introduction of solar heat (above 800 K) in the steam-reforming of natural gas, oil or other fuels. It is currently the dominant technology for producing hydrogen, and about 40% of the feedstock needs to be burned to supply process heat. Another option is the solar-assisted steam-gasification of coal or other solid fuels. CO_2 emissions would be reduced from the outset, and their capture and storage largely facilitated. Capture would be even trivial with solar-assisted thermal decomposition of fuels, preferably gaseous or liquids, which yields a carbon-rich condensed phase and a hydrogen-rich gas phase, offering a natural phase separation.

Requiring greater research and development efforts, hydrogen production is possible in the longer term without any contribution from other fuels, via solar thermochemical processes. The chemical products from any of these power generating processes are metal oxides which, in turn, need to be reduced and recycled. The conventional extraction of metals such as zinc, iron, magnesium, and other from their oxides by carbothermic and electrolytic processes discharges vast amounts of greenhouse gases and other pollutants to the environment, derived mainly from the combustion of fossil. These emissions can be substantially reduced, or even completely eliminated, by using concentrated solar energy as the source of high temperature process heat.

2.3.4 Others

2.3.4.1 Evacuated tubes

Evacuated tube collectors[27] are now being adapted to efficient operation at up to 185 °C. They are going to be widely explained in the subchapter: 2.4.3.1 Collectors.

Some specific evacuated tube collectors will be suitable for use with a new generation of organic Rankine cycle (ORC) turbines. In these, a micro turbine generator is driven by a closed loop of organic working fluid. The working fluid is heated to produce vapour, which drives a micro generator, and then condenses back to a liquid whence the cycle recommences. The overall efficiency of the system is about 7% and the electricity costs seem close to that of photovoltaic. However, this technology may offer more dispatchable or even round-the-clock electricity thanks to affordable heat storage and thus compete with photovoltaic.

2.3.4.2 Solar Ponds

In a solar pond, layers of water with increasing salt content fill a shallow pond. The sun's rays are absorbed in the lower layers of the pond. The temperature gradient between the upper and lower layers of the pond drives a heat engine. This system is simple and relatively low cost; its primary disadvantage is low solar conversion efficiency (under 1%).

The different types of ponds and how solar thermal energy can be extracted, is explained inside chapter 2.4.3.1 Collectors, in *Low temperature collectors* part.

2.3.4.3 Ocean thermal energy

Ocean thermal energy conversion (OTEC) involves capturing the energy from the temperature difference between warm surface water in tropical and subtropical latitudes and the colder water at depths of 1000 m or greater.

From a theoretical standpoint, ocean currents offer an immense source of renewable energy, but cost estimates vary widely. The initial applicability will likely be for

[27] These collectors will be broadly explained in the following subchapters.

tropical island nations where power is presently provided by expensive diesel generators.

2.3.4.4 Solar Chimneys

A solar updraft tower power plant, sometimes also called solar chimney, is a solar thermal power plant that combines a solar air collector and a central updraft tube to generate a solar induced convective flow which drives pressure staged turbines to generate electricity. A diagram is shown in Figure 2.3.2.

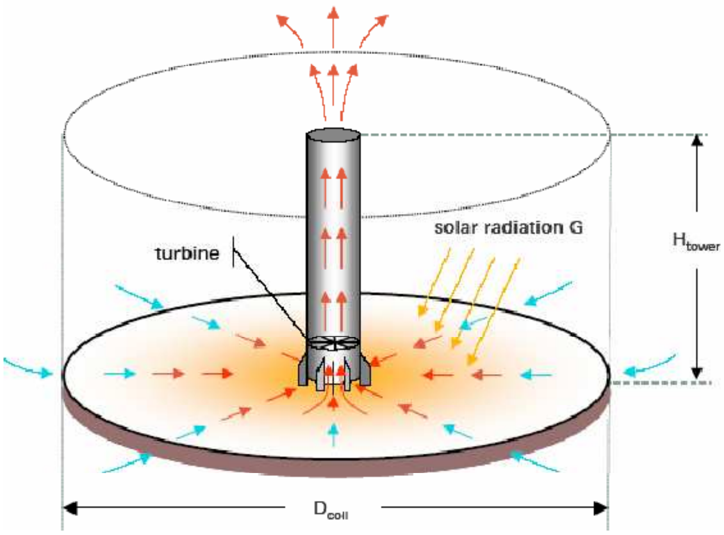


Figure 2.3.2. Solar tower updraft.

2.3.5 Economical view

Interest in solar energy was stimulated in the 1970s by high oil prices and has been further encouraged by government policies, such as tax credits. Enthusiasm diminished in the 1980s and 1990s as the prices of oil and natural gas fell and many government subsidies lapsed. After the late 1990s interest was renewed by rising energy prices, but the use of solar energy remains limited. In *Renewable Energy* (2002), the International Energy Agency estimates that in the year 2000, solar heating made up 0,3 percent of world energy consumption and photovoltaic cells contributed less than 0,05 percent.

The major impediment to solar energy is cost. Though solar radiation is abundant and non-polluting, the equipment required, to gather and utilize it, is expensive. Solar heating systems have found some commercial adoption in sunny locations for certain applications, especially for heating swimming pools. CSP technologies, though technologically proven, are not yet competitive with other sources of electricity. Perhaps the most promising technology is photovoltaics. By 2002, photovoltaic costs had fallen to about 20 to 30 percent of their 1980 levels. They have become cost-effective in some specialized applications, particularly in remote locations far from existing power lines. From 1992 to 2003, installed photovoltaic capacity worldwide grew by about 30 percent annually.

Economic theory predicts that as exhaustible energy resources are depleted, their prices will tend to rise, making renewable sources more attractive over time. The long run prospects for solar energy will depend on how its cost compares with other energy sources.

(International Encyclopedia of the Social Sciences, 2008) & (Philibert, 2005)

2.4 Solar thermal installations

From all the solar technologies that exist, the area of interest for this thesis is the solar thermal energy. There are different types of solar heating systems, these installations are going to be explained and therefore its components and how they work.

2.4.1 Types of solar thermal installations

They differ depending on the needs and the availability of the source. In one hand, about the needs, for example, it has to be considered the water temperature: if it is for DHW or domestic heating, it is desirable to have water at 60ºC; but if it is for Heating, Ventilating and Air Conditioning (HVAC) using absorption chillers, 75-90ºC are required. In the other hand, depending on the availability, environmental characteristics must be taken into account, for instance: the solar radiation at ground level, the dry-bulb temperature[28], wind speed, etc.

These installations are listed as follows, depending on its use:

2.4.1.1 Domestic-residential use

- Production of domestic hot water (DHW)

Domestic hot water is considered the water for various home uses such as laundry, showering, or hand washing. The delivered product, heated water at a point of hot water use (outlet point), is supplied by piping and water heating equipment situated within the home. They way of producing this water can be done by active (the water flow is forced) or passive (natural flow of the fluid due to gravity) systems.

- Pool heating

Pools can be heated by a solar heating system arranged by collector, or either using pool covering systems, whether solid sheets or floating disks, act as solar collectors and provide pool heating benefits.

- Space Heating

Heating and conditioning of the atmosphere inside buildings.

2.4.1.2 Industrial use

- Heat for industrial processes
- Desalination of water by evaporation

Over 60 percent of the world's desalinated water is produced using heat to distill fresh water from sea water. The distillation process mimics the natural

[28] Dry-bulb temperature (T_{db}): usually referred to as air temperature, is basically the ambient air temperature, and is the most common used air property. It is called "Dry Bulb" because the air temperature is indicated by a thermometer not affected by the moisture of the air. Can be measured using a normal thermometer freely exposed to the air but shielded from radiation and moisture (The Engineering ToolBox).

hydrologic cycle in that sea water is heated, producing water vapour, which is in turn condensed to form fresh water (Schutt, 2003).

- Solar power production

2.4.1.3 Agricultural use

The most common and widely used are the solar greenhouses.

(Departamento de Ingeniería Térmica y Fluidos, 2004)

2.4.2 Types of solar domestic water heating systems

There are many different types of SWHS, and they can be classified according to different criteria:

2.4.2.1 Water circulation

Depending on how the water circulates along the circuit, the system can be passive or active.

Active

Active systems use electric pumps, valves, and controllers to circulate water or other heat-transfer fluids through the collectors. They are usually more expensive than passive systems but generally more efficient. Active systems are often easier to retrofit than passive systems because their storage tanks do not need to be installed above or close to the collectors. They are the most widely used.

Passive

Passive systems move household water or a heat-transfer fluid through the system without pumps. Passive systems have the advantage that electricity outage and electric pump breakdown are not issues. This makes passive systems generally more reliable, easier to maintain, and possibly longer lasting than active systems. Passive systems are often less expensive than active systems, but are also generally less efficient due to slower water flow rates through the system.

There are two main passive systems:

- Thermosiphon system

Relies on warm water rising, known as natural convection, to circulate water through the solar absorber and to the tank. In this type of installation, the tank must be located above the absorber tubes/panel. As water in the absorber heats, it becomes lighter and naturally rises into the tank above. Meanwhile, cooler water in the tank flows downwards into the absorber, thus causing circulation throughout the system. The disadvantages of this design are the poor aesthetics of having a large tank on the roof and the issues with structural integrity of the roof. Often the roof must be reinforced to cope with the weight of the tank.

- Batch Heaters

Batch heaters are simple passive system consisting of one or more storage tanks placed in an insulated box that has a glazed side facing the sun. Figure 2.4.1. represents this kind of system. Batch heaters are rather cheap, but only perform well in regions where the temperature does not fall below zero.

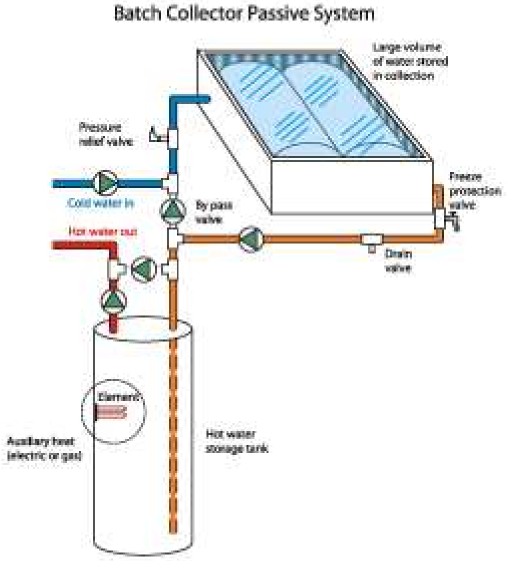


Figure 2.4.1. Batch collector passive system.

2.4.2.2 Heat transfer

This classification criterion is based on how the heat transferred is performed from the collector to the consumption point. They are divided in open loop systems, also called direct, or closed loop systems, also called indirect.

Indirect systems

In these systems, there are two circuits, each one transporting a different fluid. One hand, there is the primary circuit, where a simple pump moves an antifreeze solution through a loop into the solar heat collector, through the collector's pipes, and out of the collector. Then, the sun-warmed antifreeze solution flows into a heat transfer unit where it warms the cool water heading into a conventional hot water tank. This cold water and the conventional tank are part of the secondary circuit, which provides the water for human consumption, without any antifreeze.

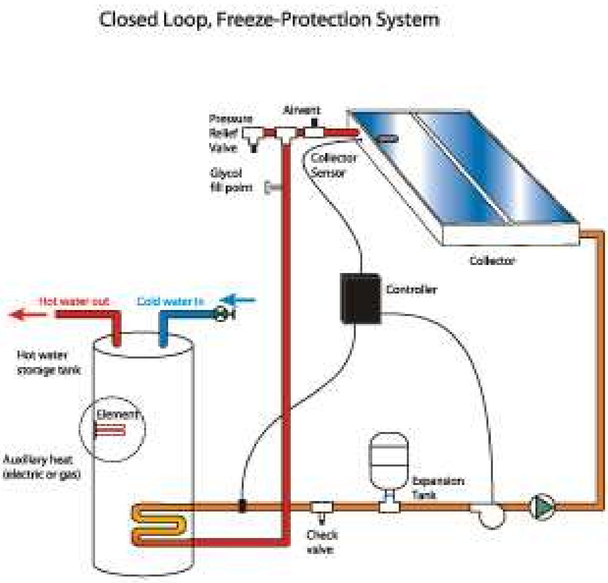


Figure 2.4.2. Indirect heat transfer system.

After passing through the heat exchanger, the antifreeze solution returns to the pump and again flows into the solar collector without ever mixing with the building’s water, as can be seen in Figure 2.4.2. Thus, water is indirectly heated. Indirect systems are encouraged in climates with extended periods of below-freezing temperatures.

Direct systems

In this case, there is no antifreeze solution; the water heated directly by the sun is the same water used by building occupants. A thermometer and controller sense when the solar collector is warm and ready to heat water. The controller starts a pump that moves cold water into the solar collector, where it is heated.

The solar heated water is then stored in a conventional hot water tank. It is typical, especially during high use or periods of little sun for the water to be kept warm through supplemental gas or electricity. This type of system, because it circulates pure, potable water through an outdoor collector, is susceptible to freezing in many climates, unless safeguards are added.

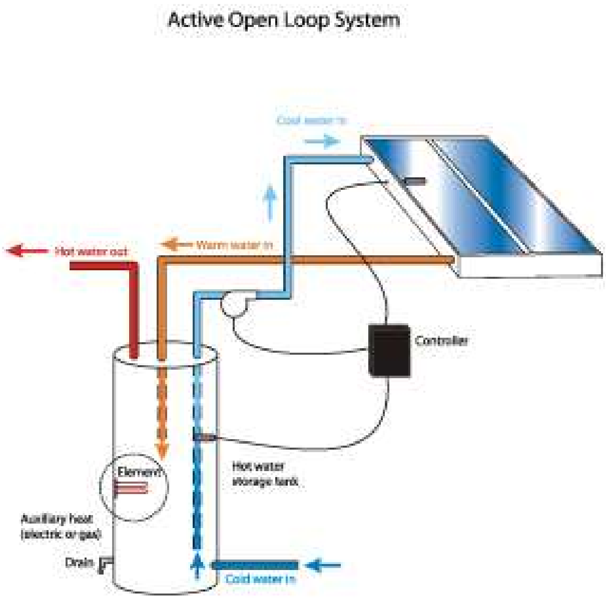


Figure 2.4.3. Active direct system.

(Apricus Solar Co., 2010) & (Southface Energy Institute, 2011)

2.4.3 Solar water heating components

A common solar water installation is described in Figure 2.4.4, in which can be seen the primary and secondary circuits, and its components.

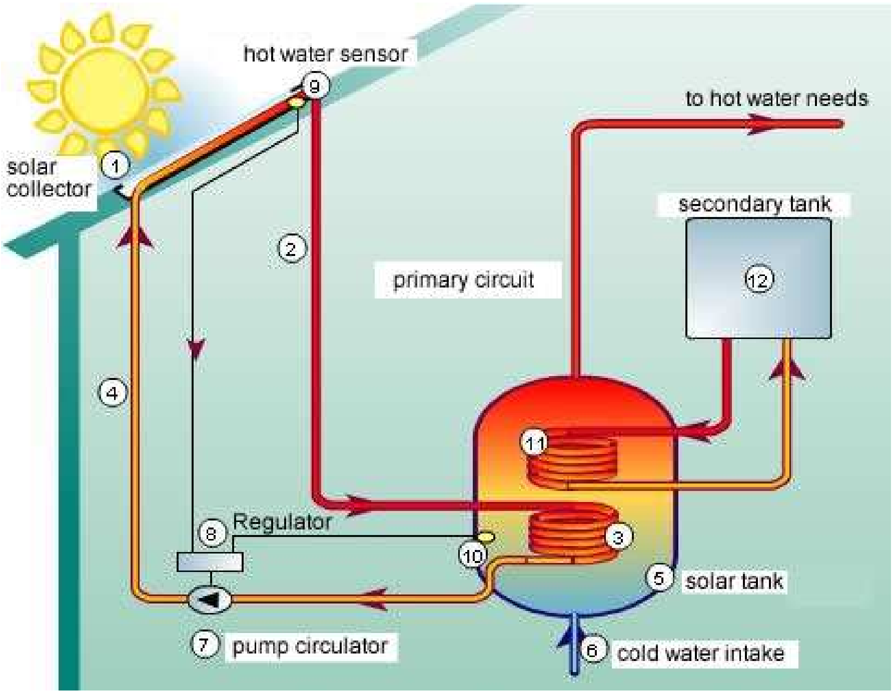


Figure 2.4.4. Solar water heating system.

(The solar water heater, 2010)

These components of a solar water heating system can be grouped in different subsystems:

1) Collecting subsystem
    i) Collectors
2) Storage subsystem
    i) Tanks and others
    ii) Heat exchangers
3) Auxiliary energy subsystem
    i) Auxiliary sources
4) Production subsystem
    i) Heat exchangers
    ii) Cooling machines
5) Others
    i) Pipes
    ii) Pumps, compressors and fans
    iii) Expansion tanks, valves, sensors, control switchboards, etc.

The main components, their different types and their theoretical approach and are going to be explained in the following subchapters.

2.4.3.1 Collectors

The collectors (1)[29] are the protagonist of the collecting subsystem. The most important and most expensive single component of an active solar energy system is the collector field.

[29] The numbering of the components refers to the numbers in Figure 2.4.4.

As it was explained in Chapter 2.2.4.1: Optimum surface orientation, and shown in Figure 2.2.20, collectors can be nontracking, one-axis tracking or two-axis tracking. Tables III.1 – 3, in Appendix III, list collector types, typical operating temperatures, current costs and additional comments.

Types of collectors

Solar thermal collectors can be divided in two types depending on the needed temperature of the water: low temperature (lower than 80ºC) and high temperature collectors (up to 120-150ºC).

Low temperature collectors

- Solar ponds

They are the most economical choices for low temperatures. However, because of high heat loss, they are quite sensitive to ambient temperature and insolation. Among solar ponds, must be distinguished two different types:

  - *Shallow solar pond*: consist of a shallow horizontal water bag, insulated by one or more plastic films and air layers. It is filled in the morning and drained into a storage tank in the evening. Because ultraviolet degradation, the outer cover of a shallow solar pond may need replacement, perhaps every 5 years.

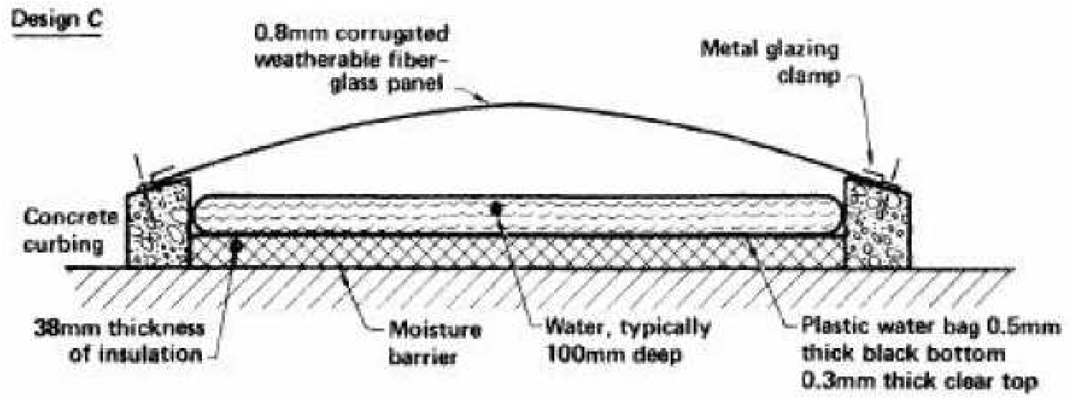


Figure 2.4.5. Cross section of a shallow solar pond module.

  - *Deep (or salt-gradient) solar pond:* uses a thick layer, about 1 m, of nonconvecting water as insulation. Convection is prevented by adding salt in such way as to establish a concentration gradient, with the saltier water at the bottom. The saltier water is heavy enough to stay at the bottom even when warmed by the sun. A layer of 1 m of nonconvecting water offers as much thermal resistance as 5 cm of Styrofoam[30], but it transmits much of the incident solar radiation. Beneath the nonconvecting layer, there is a convecting layer of salt water for thermal storage and heat extraction; its thickness is in the range of 0,2 – 2 m, depending on the desired amount of storage.

[30] Styrofoam: trade name of foamed polystyrene plastic, which is a polymer of styrene (The Columbia Encyclopedia, Sixth Edition, 2008).

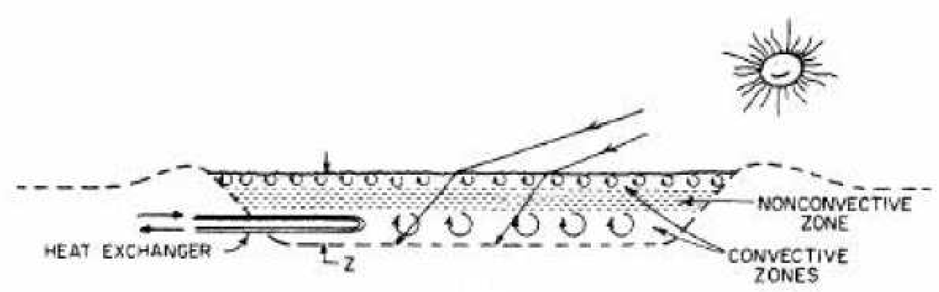


Figure 2.4.6. Cross section of a deep solar pond, showing three-zone configuration.

Both deep and shallow solar ponds perform well in sunny and southerly locations. In cloudier climates the achievable operating temperature may be too low to be interest to industry; however, for space heating, the deep solar pond may be attractive for apartment complexes and district heating systems.

Deep solar ponds combine collector and long-term storage into a single low-cost element and are currently the only suitable candidate for stand-alone solar installations.

(Rabl, 1985)

- Flat plate collectors

They form the heart of most solar-powered living space and domestic hot water systems. They are the best-developed collectors and cost reductions are difficult to achieve (Rabl, 1985). The concept of a collector is simple: provide a dark surface to absorb as much solar energy as practical and include means to transport the collected energy without serious loss for either immediate needs elsewhere or storage for later use. Components of a solar collector include some or all of the following:

  - A surface (typically a metal sheet) that is black to absorb nearly all the incident solar energy.
  - One or more glazing sheets to transmit solar radiation readily to the absorber plate while intercepting and reducing thermal radiation and convection heat loss to the environment.
  - Tubes or ducts to transport a fluid through the collector to accumulate the solar heat and transfer that heat out of the collector.
  - Structure (basically a box) to hold and protect the components and withstand weather.
  - Insulation placed on the sides and behind the absorber plate that reduces parasitic heat loss.

There are three common flat-plate collectors, one that uses liquid, a second that uses air, and a third, unglazed. Glass is typically the material of choice for solar collector glazing, although plastic may be used. Glass withstands weather better than plastic and does not lose transmittance due to yellowing or surface degradation. Glass with low iron content (i.e., 0,002 to 0,10% Fe_2O_3) transmits a greater solar radiation fraction, which can increase collector efficiency by several percent.

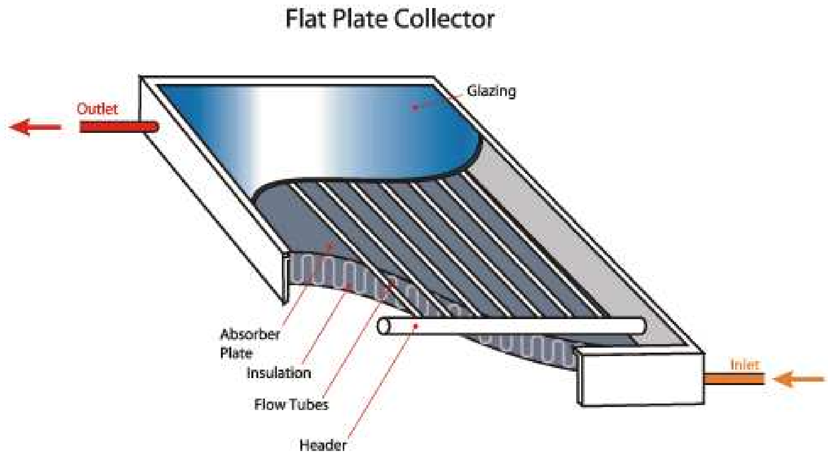


Figure 2.4.7. Flat plate collector components.

(Southface Energy Institute, 2011)

- <u>Solar collectors with liquid as the transport fluid:</u>

Water as a heat transport fluid has several advantages: its relatively high volumetric heat capacity[31] and high specific heat[32], its relative incompressibility, and its relatively high mass density, permitting use of small tubes and pipes for transport. However, water freezes well within the winter temperature range of colder climates. And freezing water can damage a solar collector and piping system.

One option to avoid freeze damage is to use a drain-down collector system that empties the system as soon as the solar input drops below some critical isolation level; but there some potential problems that are reasons to avoid drain-down collector systems for most applications in cold climates.

An alternate strategy is to add antifreeze to the water, which is generally the preferred choice. The typical antifreeze fluid is either ethylene glycol (which is toxic, requiring double-walled, closed loop systems) or propylene glycol, mixed with water. Either fluid must be adjusted to the proper concentration for adequate freeze protection. It must be taken into account that antifreeze can degrade over the time and lose effectiveness.

- <u>Solar collectors with air as the transport fluid:</u>

These collectors are usually better suited for space heating (or heating ventilation air) and drying crops in agriculture. Although most applications will require a fan to move the air, carefully designed collector can be integrated into building systems to provide passive movement of the warmed air to the heated space, with a return flow of cooler air.

Heat transfer from a solid to air by convection is significantly less vigorous than is heat transfer from solid to liquid.

[31] Water's volumetric heat capacity: 4186 kJ/m^3K, at 25ºC.

[32] Water's specific heat: 4186 $(J \cdot kg \cdot K)^{-1}$, at 25ºC.

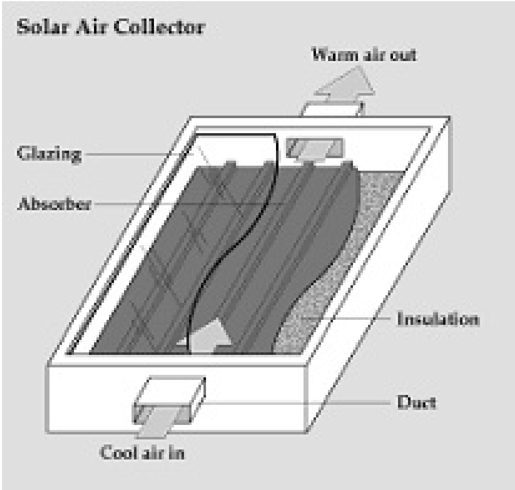


Figure 2.4.8. Collector with air as the transport fluid.

(Pennsylvania Weatherization Providers)

(Vanek & Albright, 2008)

- Unglazed collectors

An unglazed collector is a solar collector that consists of an absorber without the glass covering of a glazed flat-plate collector. Because they are not insulated, these collectors are best suited for low temperature applications where the demand temperature is below 30°C.

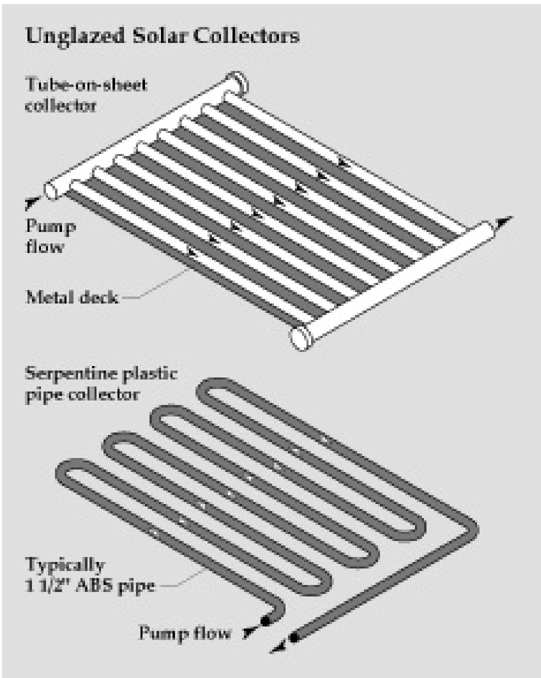


Figure 2.4.9. Unglazed solar collectors.

(Pennsylvania Weatherization Providers)

By far, the primary market is for heating outdoor swimming pools; the temperatures are so low that unglazed collectors may be the most cost effective (Rabl, 1985). But other markets exist including heating seasonal indoor swimming pools, pre-heating water for car washes, and heating water used in fish farming operations. There is also a market potential for these collectors for water heating at remote, seasonal locations such as summer camps.

Unglazed collectors are usually made of black plastic that has been stabilized to withstand ultraviolet light. Since these collectors have no glazing, a larger portion of the sun's energy is absorbed. However, because they are not insulated a large portion of the heat absorbed is lost, particularly when it is windy and not warm outside. They transfer heat so well to air (and from air) that they can actually capture heat during the night when it is hot and windy outside.

(The Encyclopedia of Alternative Energy and Sustainable Living)

- Integral collector-storage systems

Also known as ICS or *batch* systems, they feature one or more black tanks or tubes in an insulated, glazed box. Cold water first passes through the solar collector, which preheats the water. The water then continues on to the conventional backup water heater, providing a reliable source of hot water. They should be installed only in mild-freeze climates because the outdoor pipes could freeze in severe, cold weather.

(U.S. Department of Energy)

High temperature collectors

Because of their high heat loss coefficient, ordinary flat plate collectors are not practical for elevated temperatures, i.e. above 80ºC. When higher temperatures are desired, one needs to reduce the heat loss coefficient. This can be accomplished principally by two methods: evacuation and concentration, either singly or in combination.

- Evacuated-Tube solar collectors

These collectors are fabricated of arrays of one or two concentric glass tubes, and connected in parallel, are housed within a protective structure for physical protection and insulation.

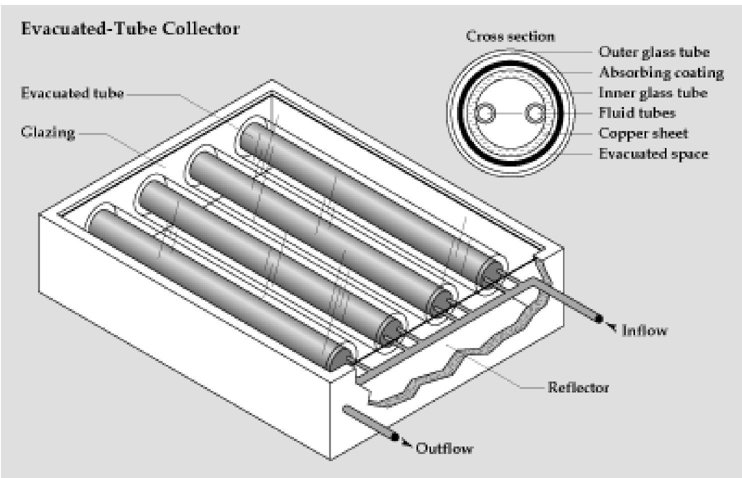


Figure 2.4.10. Evacuated tube collector and its cross section.

(The Encyclopedia of Alternative Energy and Sustainable Living)

The main characteristics of these collectors are:

- The evacuated tubes block convective heat loss from the absorber.
- Efficiency is generally higher than typical for flat-plate solar collector.

- They are excellent for operating temperatures up to the 120-150ºC range. This permits useful applications for process heat in commercial applications and absorption refrigeration systems for solar air conditioning, as examples.
- They are also suitable for domestic hot water and may be preferred for northern climates where very cold winters and the resulting greater heat loss make flat-plate solar collectors less efficient.
- The evacuated tube reduces heat loss from the absorber plate, making this design possibly useful on cloudy days when normal flat-plate collectors may not reach a temperature adequate for useful collection.
- Evacuated tubular collectors are hermetically sealed and contain getters to absorb any molecules that outgas into the vacuum.
- However, the greater insulation value of an evacuated tube solar collector slows the rate of snowmelt from the collector panel, reducing collector efficiency on days following snowfall.
- The tubes are expected to have a maintenance free lifetime on the order of 20 years.
- They are nontracking.
- Many of them use some kind of reflector enhancement.
- They have great potential for cost reduction through mass production, but the investment required to build efficient production facilities is too large to be justified by present demand.

(Vanek & Albright, 2008) & (Rabl, 1985)

There are several types of evacuated tubes:

- <u>Type 1 (Glass-Glass) tubes</u>

This type consists of two glass tubes which are fused together at one end. The inner tube is coated with a selective surface that absorbs solar energy well but inhibits radiative heat loss. The air is withdrawn, or evacuated, from the space between the two glass tubes to form a vacuum, which eliminates conductive and convective heat loss. These tubes perform very well in overcast conditions as well as low temperatures. Because the tube is 100% glass, the problem with loss of vacuum due to a broken seal is greatly minimized. Glass-glass solar tubes may be used in a number of different ways, including direct flow, heat pipe, or U pipe configuration.

- <u>Type 2 (Glass-Metal) tubes</u>

Consist of a single glass tube. Inside the tube is a flat or curved aluminium plate which is attached to a copper heat pipe or water flow pipe. The aluminium plate is generally coated with TiNOX[33], or similar selective coating.

(Apricus Solar Co., 2010)

The heat pipe is hollow and the space inside, like that of the solar tube, is evacuated. The reason for evacuating the heat pipe, however, is not insulation but to promote a change of state of the liquid it contains. Inside the heat pipe is a small quantity of liquid, such as alcohol or purified water

[33] Absorber TiNOX: Is a part of a Solar Company. This absorber takes up the energy in sunlight and converts it into heat. The more efficient the absorber, the greater the collector's output. (Almeco Tinox Solar, 2011)

plus special additives. The vacuum enables the liquid to boil (i.e. turn from liquid to vapour) at a much lower temperature than it would at normal atmospheric pressure. When solar radiation falls the surface of the absorber, the liquid within the heat tube quickly turns to hot vapour rises to the top of the pipe. Water, or glycol, flows through a manifold and picks up the heat, while the fluid in the heat pipe condenses and flows back down the tube for the process to be repeated.

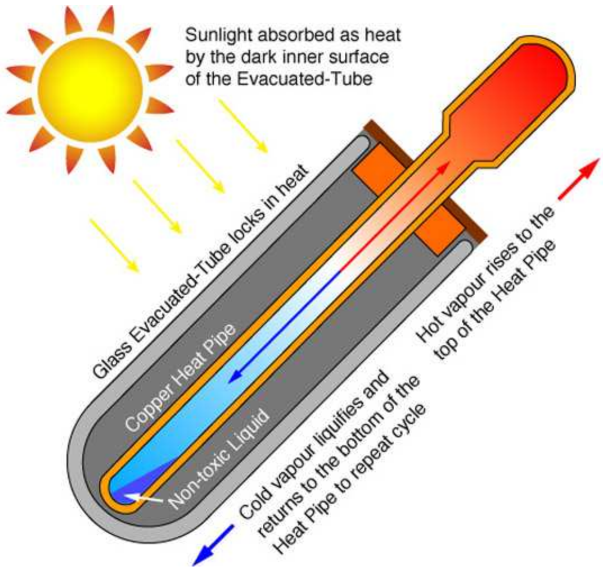


Figure 2.4.11. Heat Pipe Evacuated tube collector.

An advantage of heat pipes over direct-flow evacuated-tubes is the "dry" connection between the absorber and the header, which makes installation easier and also means that individual tubes can be exchanged without emptying the entire system of its fluid. And the drawback of heat pipe collectors is that they must be mounted with a minimum tilt angle of around 25° in order to allow the internal fluid of the heat pipe to return to the hot absorber.

(The Encyclopedia of Alternative Energy and Sustainable Living)

These type of tubes are very efficient but can have problems relating to loss of vacuum. This is primarily due to the fact that their seal is glass to metal. The heat expansion rates of these two materials. Glass-glass tubes although not quite as efficient glass-metal tubes are generally more reliable and much cheaper.

- Type 3 (Glass-glass - water flow path) tubes

These tubes incorporate a water flow path into the tube itself. The problem with these tubes is that if a tube is ever damaged water will pour from the collector onto the roof and the collector must be "shut-down" until the tube is replaced.

(Apricus Solar Co., 2010)

- Concentrating collectors

Concentrating collectors for are usually parabolic troughs that use mirrored surfaces to concentrate the sun's energy on an absorber tube containing a heat-transfer fluid, or the water itself. Concentrating solar collectors follow three main designs: parabolic troughs and dishes, nonimaging solar concentrators, and central receivers (power towers).

This type of solar collector is generally used for commercial power production applications, industrial processes, absorption chilling and solar air conditioning; because very high temperatures can be achieved. It is however reliant on direct sunlight and therefore does not perform well in overcast conditions.

These collectors are not going to be deeply explained as they are not used for DHW systems, and therefore they are not the object of study of this thesis. Also, the basics of these collectors have been explained in Chapter 2.3.2. Solar Power.

(Apricus Solar Co., 2010) & (Vanek & Albright, 2008)

Calculus of solar collectors

The actual useful energy gain of a collector is expressed in Equation 2.4-1.

$$Q_u = A_c \cdot F_R \cdot \left[S - U_L \cdot \left(T_{f,i} - T_a\right)\right]$$

Equation 2.4-1

Where each component means:

- Q_u is the actual useful energy gain [J]
- A_c is the collector area [m^2]
- S is the absorbed solar radiation, and is a function of the incident solar radiation, I_T, and the transmittance-absorptance product, $(\tau\alpha)$. [J/ m^2]
- U_L is the collector overall loss coefficient [W/ m^2 C]
- $T_{f,i}$ is the fluid inlet temperature [K] or [ºC]
- T_a is the ambient temperature [K] or [ºC]
- And F_R is the collector heat removal factor

This removal factor is the quantity that relates the actual useful energy gain of a collector to the useful gain if the whole collector surface was at the fluid inlet temperature, and mathematically is given by:

$$F_R = \frac{\dot{m}C_p\left(T_{f,o} - T_{f,i}\right)}{A_c\left[S - U_L\left(T_{f,i} - T_a\right)\right]} = \frac{\dot{m}C_p}{A_c U_L}\left[1 - e^{-\left(A_c U_L F'/\dot{m}C_p\right)}\right]$$

Equation 2.4-2

Where:

- $\dot{m}$ is the total collector flow rate [kg/s]
- C_p is the specific heat of the fluid [J/kg K]
- $T_{f,o}$ is the fluid outlet temperature [K] or [ºC]
- F' collector efficiency factor

Equation 2.4-3 shows the expression of the collector efficiency factor, where $1/U_0$ is the heat transfer resistance from the fluid to the ambient air [m^2 C/W]

$$F' = \frac{U_0}{U_L}$$

Equation 2.4-3

(Duffie & Beckman, 1980)

Applications of collectors

A collector is defined by two parameters: "$F_R\,(\tau\alpha)$" and "$F_R\,U_L$" [34]. The larger $F_R\,(\tau\alpha)$ is, the more efficient the collector is at capturing the energy from solar radiation. And the smaller $F_R\,U_L$ is, the better the collector is at retaining the captured energy instead of losing it through convection and conduction to the ambient air.

Depending on which value these parameters have, the collectors can be classified in four types:

- Group I: Unglazed collectors, without insulation, usually made of plastic.
  - $0{,}85 < F_R\,(\tau\alpha) < 0{,}90$
  - $16 < F_R\,U_L < 20$ [W/ºC·m²]
- Group II: Glazed collectors, insulated and one transparent cover.
  - $0{,}75 < F_R\,(\tau\alpha) < 0{,}85$
  - $7 < F_R\,U_L < 9$ [W/ºC·m²]
- Group III: Glazed collectors, insulated, one transparent cover and selective absorbent surface.
  - $0{,}75 < F_R\,(\tau\alpha) < 0{,}85$
  - $5 < F_R\,U_L < 6$ [W/ºC·m²]
- Group IV: Glazed collectors, insulated and two transparent covers.
  - $0{,}7 < F_R\,(\tau\alpha) < 0{,}8$
  - $4 < F_R\,U_L < 6$ [W/ºC·m²]

The applications depending on the group they belong are:

- Group I is used when $\Delta T = T_{f,i} - T_a < 15$ ºC for: pool heating, as cold source in a heat pump, industrial processes, etc.
- Groups II and III are used when $10 < \Delta T < 40$ ºC, for: DHW, heating in mild climates, agricultural use, industrial use, etc.
- Groups III and IV are used for: DHW, heating in cold climates, industrial processes, etc.

(Colectores de placa plana [Flat plate colectors], 2009)

Connection between collectors

Collector modules can be in parallel, series (as shown in Figure 2.4.13), or a combination series-parallel The flow is divided in the parallel set, but in series set the full flow goes through each module.

The performance of the modules will be dependant of the connection set by the inlet temperatures of the fluid, and the flow rate, which varies if it is series or parallel. The most important effect is the increase of inlet temperature of the fluid along the flow path in collector series module.

[34] These parameters are the same that are going to be in used in RETSCreen to decide, in the analytical part, which collector will be installed for the simulation of the solar system.

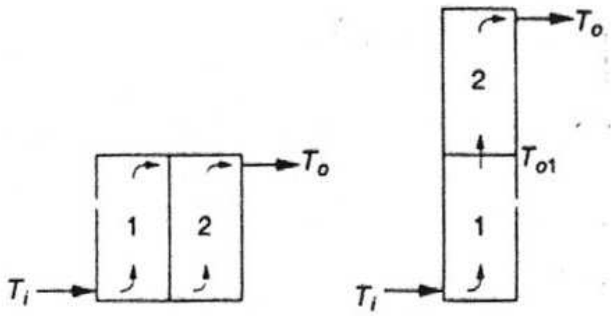


Figure 2.4.12. Collector modules in parallel (left) and series (right).

(Duffie & Beckman, 1980)

(Departamento de Ingeniería Térmica y Fluidos, 2004)

2.4.3.2 Tanks

The tank (5) represents the main part of the storage subsystem. The main type of thermal energy storage is the water-based.

The tank is a recipient made usually of steel with an insulation based on polyurethane. The inlet tube from the collectors is placed at the bottom, and the outlet to the consumption water network is at the top of the tank. This is the stratification concept inside the tank, which is useful because the aim is to serve the water with the maximum possible temperature, and return the cold water to the collectors as cold as possible, for that its performance is increased.

Advantages of water as a way of storage

- Most common fluid
- Good qualities for its use in solar collectors and as heat storage.
- High heat capacity and remains liquid in the usual temperature range in flat plate collectors.
- Excellent transportation properties: viscosity, thermal conductivity, density, etc.
- Not toxic, neither inflammable.
- Cheap

Disadvantages of water

- Catalytic of electrolytic corrosion when different metals are used.
- Freeze at 0 ºC, and its volume increase.
- Boils at 100 ºC at ambient pressure.
- Good dissolvent: dissolves oxygen, which improves the corrosion.

Calculus of tanks

The stored thermal energy is: $Q_s = (m \cdot C_p)_s \cdot \Delta T_s$ [J]; where $(m \cdot C_p)_s$ is the heat capacity of the storage system.

(Departamento de Ingeniería Térmica y Fluidos, 2004)

2.4.3.3 Heat exchangers

They are used in indirect systems. There are many types of heat exchangers, but the main configurations are explained below.

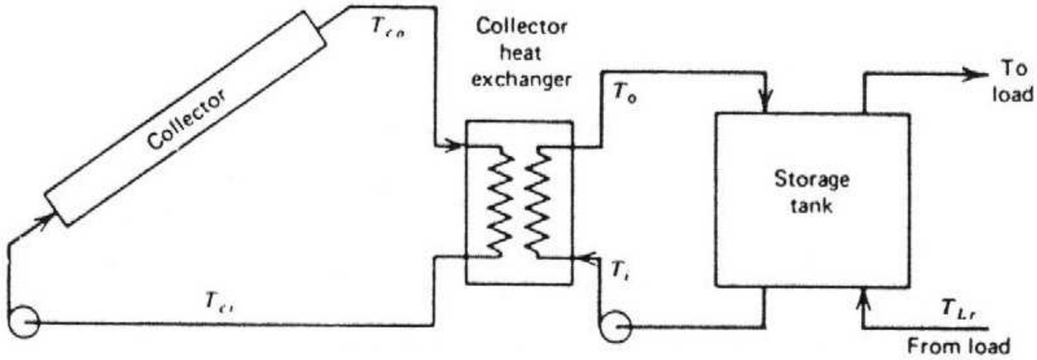


Figure 2.4.13. Independent heat exchanger in an indirect system.

Types of heat exchangers

- Independent heat exchanger through which flows: in one side the collector fluid and in the other side the storage fluid from the tank. Figure 2.4.14 represents the basic configuration of an indirect system with an independent heat exchanger. Usually it is a plate heat exchanger, but it can be also shell and tube or plate fin heat exchanger.

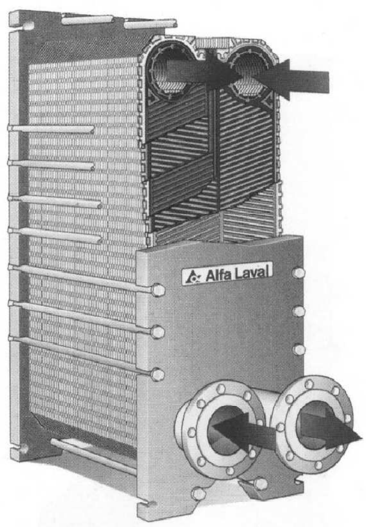


Figure 2.4.14. Plate heat exchanger.

- A coil integrated inside the tank (3 and 11); inside it the fluid from the collectors flows.

Calculus of heat exchangers

The heat exchanger performance is expressed in terms of effectiveness by:

$$Q_{HX} = \left(\dot{m}C_p\right)_{min} \varepsilon \cdot \left(T_{c,o} - T_i\right)$$

Equation 2.4-4

Where the components mean:

- $\left(\dot{m}C_p\right)_{min}$ is the smaller of the fluid capacitance rates [J/s K] (flow rate, $\dot{m}$ [kg/s], times fluid heat capacity, C_p [J/kg K])
- ε is the heat exchanger effectiveness. ε = f (NTU, $\left(\dot{m}C_p\right)$, type of heat exchanger)

- NTU is the number of transfer units
- $T_{c,o}$ is the outlet fluid temperature from the collector [K] or [ºC]
- T_i is the inlet water temperature to the heat exchanger [K] or [ºC] (the temperature in the bottom of the tank)

(Departamento de Ingeniería Térmica y Fluidos, 2004) & (Duffie & Beckman, 1980)

2.4.3.4 Auxiliary sources

As not all the DHW demand can be covered by the solar installation, due to clouds or climate conditions, there is a need of an auxiliary source to cover this demand. The auxiliary sources (12) are part of the energy subsystem.

Auxiliary energy

This extra energy needed is provided by:

- Gas, Natural gas or electric boiler
- Electric resistances.

Auxiliary systems location

Figure 2.4.16 represents the alternative locations for this auxiliary energy.

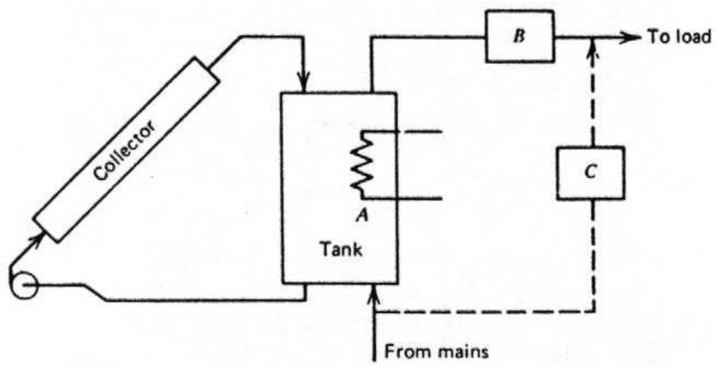


Figure 2.4.15. Alternative locations for auxiliary energy supply in an active system.

A. Coil or resistances inside the tank, on the upper part relying on the stratification. Is the most cheap and simple way, but the performance usually decreases.
B. Heat addition to the water that leaves the tank, increasing the temperature till the service level (60ºC). This can be performed with the heater connected in series or with an extra tank. Is the best option.
C. Straight auxiliary energy, substituting the solar heated water when the temperature of the tank is not enough. Simple but does not use the solar energy just because the temperature doesn’t reach the service temperature.

(Departamento de Ingeniería Térmica y Fluidos, 2004)

2.4.3.5 Pipes and ducts

Materials

For liquid transportation, the materials of the pipes can be:

- Copper: cheap, easy to manufacture, low head loss, big resistance to corrosion.

- Galvanized steel: until 65ºC, only for secondary circuits.
- Plastic: for small diameters, cheap, must resist more than 120 ºC.

Calculus

The energy lost from ducts and pipes leading to a returning from the collector in a solar energy system can be significant. The duct and pipe loss factors are expressed by:

$$HL = U_d(A_i + A_o) \cdot (T_i - T_a) + \frac{U_d A_o Q_u}{\left(\dot{m}C_p\right)_c}$$

Equation 2.4-5

- *HL* head loss [J]
- U_d id the loss coefficient from the duct
- A_i area for heat loss of the inlet duct [m^2]
- A_o area for heat loss of the outlet duct [m^2]
- $\left(\dot{m}C_p\right)_c$ collector fluid capacitance rate [J/s K]

(Departamento de Ingeniería Térmica y Fluidos, 2004) & (Duffie & Beckman, 1980)

2.4.3.6 Expansion tanks

The circuits must be able to absorb the dilatations of the fluids that flow through them.

How they work

Figure 2.4.17 shows the working phases of an expansion tank.

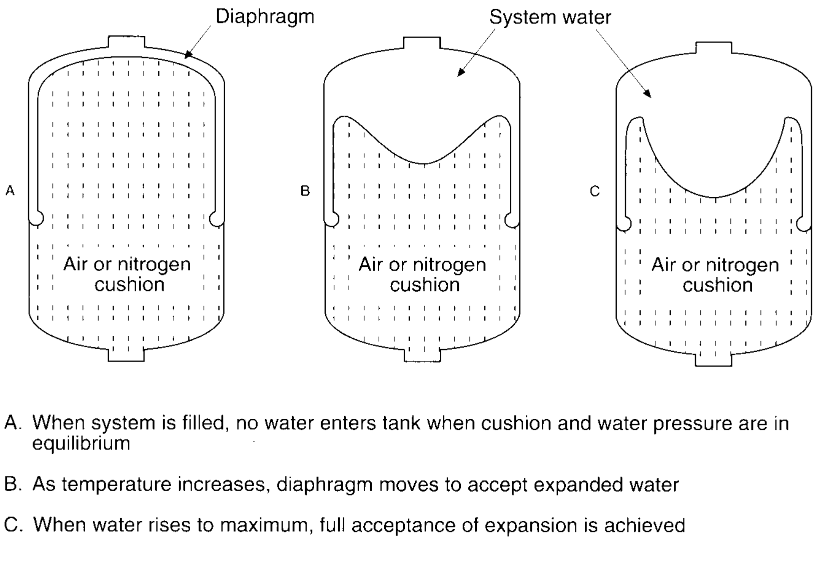


Figure 2.4.16. Phases of a expansion tank.

(Rockhill, 1995)

Types of expansion tanks

- Open: they transfer the vapours to the atmosphere.
- Closed: they are better because they can be placed almost everywhere, do not absorb oxygen from the air and avoid water losses.

2.4.3.7 Safety components

The basic components that are used for safety reasons and to control the installation are:

- Valves.
- Thermostats.
- Sensors: photodetector, thermocouple, RTD (Resistance Temperature Detector).
- Control switchboards.
- Etc.

3 Finnish and Spanish situation

3.1 Introduction

These two countries that are going to be analyzed, Finland and Spain, are geographically far away from each other measuring from the equator. They are in different latitudes; therefore, the solar irradiance that each one is going to receive annually is different.

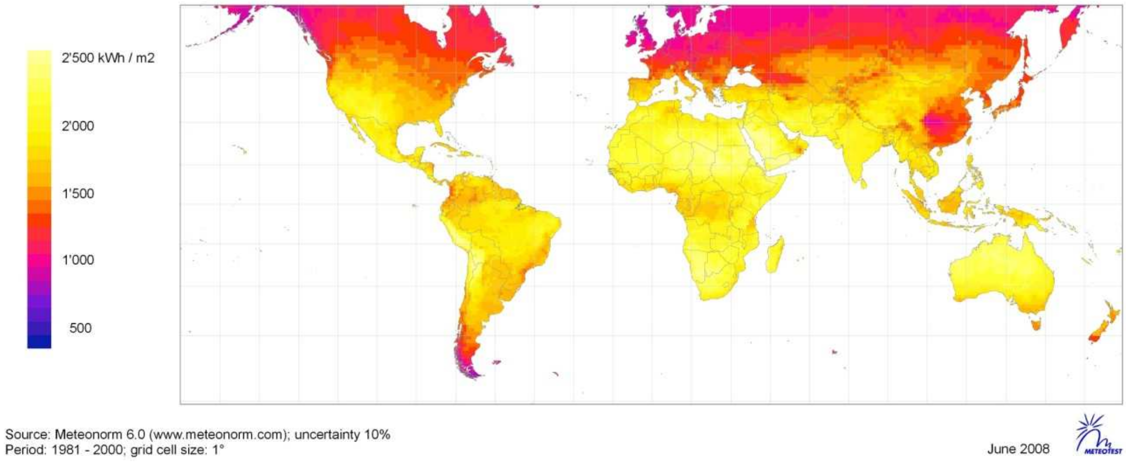


Figure 3.1.1. World map of the yearly sum of global irradiance.

(Meteotest, 2008)

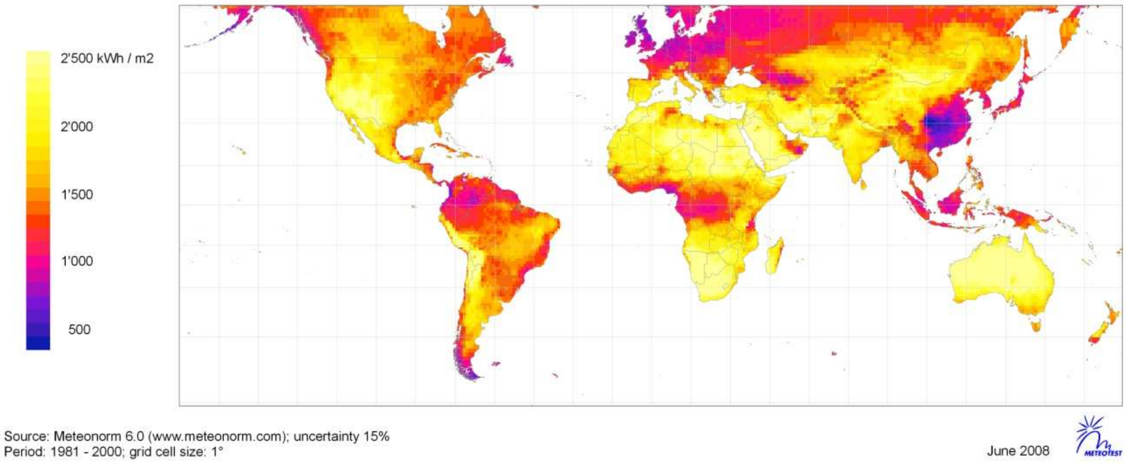


Figure 3.1.2. World map of the yearly sum of direct irradiance.

(Meteotest, 2008)

Figures 3.1.1 and 3.1.2 show various maps with average annual energy values on fixed, due-south facing surfaces that are optimally inclined, in the world. It has to be taken into account the effects of intermittency and annual variations.

These graphs highlight the differences between direct, or beam, and global irradiance where "global" includes diffuse light. There can be seen the areas with a high proportion of diffuse light include Northern Europe, South-East China and the tropical belt around the equator.

3.1.1 The effect of intermittency

If we assume a peak intensity of 960W/m^2, the ratio of the average intensity to the peak intensity in Europe is between 12% (Iceland) – 24% (Southern Spain) with the average around 18%. This is a measure of the intermittency of the solar energy source. It also means that solar systems have to be built to cope with peak intensity, but will on average only be able to convert 18% of that peak. This factor is closely related to the so-called capacity factor.

3.1.2 Annual Variation of solar insolation

The energy (or insolation) received on a surface throughout the year varies relatively little from year to year.

Intuitively, more energy comes from the time intervals with high irradiation. The contribution of highly intense light can vary significantly from one year to another. The standard deviation of the overall annual energy, however, is around ±4%. I.e. the annual energy delivered by the sun does not vary greatly year on year. The sun provides a stable "traffic".

(Green Rhino Energy, 2010)

Focusing on Europe, Figure IV.A.1. inside Appendix IV.A: Data in Europe, illustrates the annual global irradiance in the continent where Spain and Finland are, that is Europe.

But, before analyzing the situation in each country, economical and environmental, is important to know and understand the European energy background.

3.2 European Regulation

The EU publishes directives, and then, the EU countries themselves must modify and bring their regulations up to date.

On the 6th of May of 2009 was published, at the Official Journal of the European Union, the *Directive 2009/28/EC of the European Parliament and of the Council of 23rd April 2009, about the promotion of the use of energy from renewable sources*. It is the latest directive about renewable energies that has been published.

This directive establishes a common framework for the use of energy from renewable sources in order to limit greenhouse gas emissions and to promote cleaner transport. To this end, national action plans are defined, as are procedures for the use of biofuels. Each Member State has a target calculated according to the share of energy from renewable sources in its gross final consumption for 2020. This target is in line with the overall '20-20-20' goal for the Community. Moreover, the share of energy from renewable sources in the transport sector must amount to at least 10 % of final energy consumption in the sector by 2020.

The Member States are to establish national action plans which set the share of energy from renewable sources consumed in transport, as well as in the production of electricity and heating, for 2020. These action plans must take into account the effects of other energy efficiency measures on final energy consumption (the higher the reduction in energy consumption, the less energy from renewable sources will be required to meet the target). These plans will also establish procedures for the reform of planning and pricing schemes and access to electricity networks, promoting energy from renewable sources.

Besides, member States have made a commitment to reduce consumption of primary energy by 20% by 2020. There are still many barriers to the implementation of effective measures. This *Communication from the Commission of 13 November 2008 - Energy efficiency: delivering the 20% target [COM (2008) 772 - Not published in the Official Journal]* describes the current position of future projects aiming to reach the ‘20-20-20’ goal.

The Energy consumption in residential and commercial buildings represents around 40% of total final energy use. It is responsible for 36% of the European Union’s total CO2 emissions. To reduce this type of consumption, steps should be taken to simplify *Directive 2002/91/EC on the energy performance of buildings*, which constitutes the current legal framework, whilst leaving some autonomy to Member States to act in this area. The European Commission proposes that the 1000 m^2 threshold for existing buildings when they undergo major renovation is eliminated and that the requirements concerning energy performance be applied to a larger number of buildings.

Related to this, must be mentioned that on *18 May 2010 a recast of The Directive on energy performance of buildings (2002/91/EC)* was adopted in order to strengthen the energy performance requirements and to clarify and streamline some of its provisions. Energy performance of buildings is the key to achieve the EU Climate & Energy objectives, namely the reduction of a 20% of the Greenhouse gases emissions by 2020 and a 20% energy savings by 2020. Improving the energy performance of buildings is a cost-effective way of fighting against climate change and improving energy security, while also creating job opportunities, particularly in the building sector.

The Directive on energy performance of buildings (2002/91/EC) is the main legislative instrument at EU level to achieve energy performance in buildings. Under this Directive, the Member States must apply minimum requirements as regards the energy performance of new and existing buildings, ensure the certification of their energy performance and require the regular inspection of boilers and air conditioning systems in buildings.

(European Union, 2009)

For more information, the directives named are of public access, and are referenced in this thesis.

About the current 2020 energy target in Europe, Table V.B.4 represents the share of renewable consumption to gross final energy consumption of the EU countries, and their percentage still to cover. In this table can be seen that the target for Finland is to achieve 38% of renewable consumption in 2020, and nowadays still 7,5% is lest to cover; and the Spanish target is 20%, from which 9,3% are still needed to fulfil to reach the 2020’s target.

3.3 Finnish situation

According to the European directives, Finland has updated its regulations for fulfilling the requirements of the EU.

In this chapter are going to be studied the background of Finland about renewable energies, its climate situation to face solar energy installations and the regulations related with this subject.

3.3.1 Renewable energies in Finland

First of all, before analyzing the energy situation in Finland, the overall energy circumstances in Finland must be known. The information has been retrieved from the International Energy Agency (IEA), Organisation for Economic Co-operation and Development (OECD) and *Tilastokeskus* [Statistics Finland].

Figure V.B.1 (inside Appendix V.B: Energy statistics in EU, section *Energy statistics in Finlan)* represents the evolution of the primary energy supply in Finland since 1972 till 2008. The primary energy supply in this year, 2008, was 35 Mtoe[35] and is represented in Figure 3.3.1.

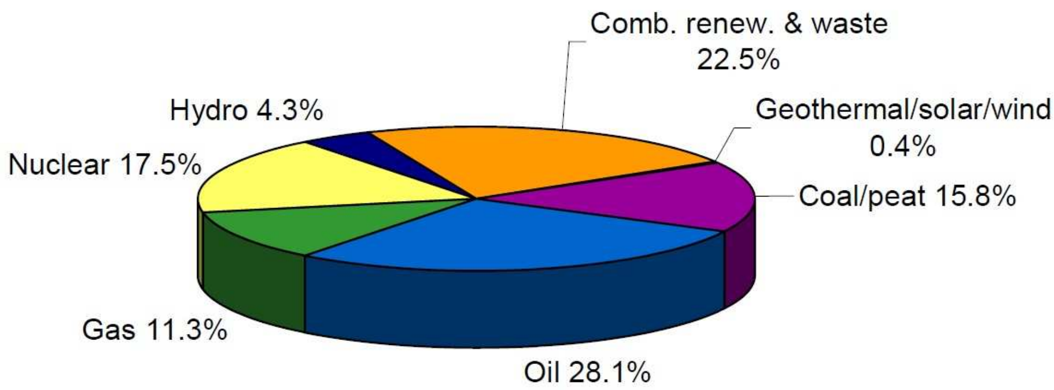


Figure 3.3.1. Share of the total primary energy supply in Finland in 2008.

In this graph can be seen that the combination of renewable energies and waste was the second primary energy supplied, with 22,5% of the total; and oil is still the first one, with 28,1%.

Besides, the energy production by Finland itself have increased during the past years, as can be seen in Figure V.B.2, being majorities the Nuclear energy and the combination of renewable and waste energy production.

However, it is interesting to know the energy consumed in Finland. Figure V.B.3 represents the evolution (1974-2008) of the final consumption by sector. As expected, Industries sector is the one that consumes more amount of energy. For better understanding of this consumption, Figure V.B.4 shows the breakdown of sectoral final consumption by source, comparing the situations in 1974 and in 2008.

(IEA/OECD, 2011)

[35] Mtoe: Million tonnes of oil equivalent. The tonne of oil equivalent (toe) is a unit of energy, and it is described as the amount of energy released by burning one tonne of crude oil, approximately 42 GJ; the exact value of the toe is defined by convention.

Nowadays, the total energy consumption by source is illustrated in Figure 3.3.2. (Data retrieved from Table V.B.5).

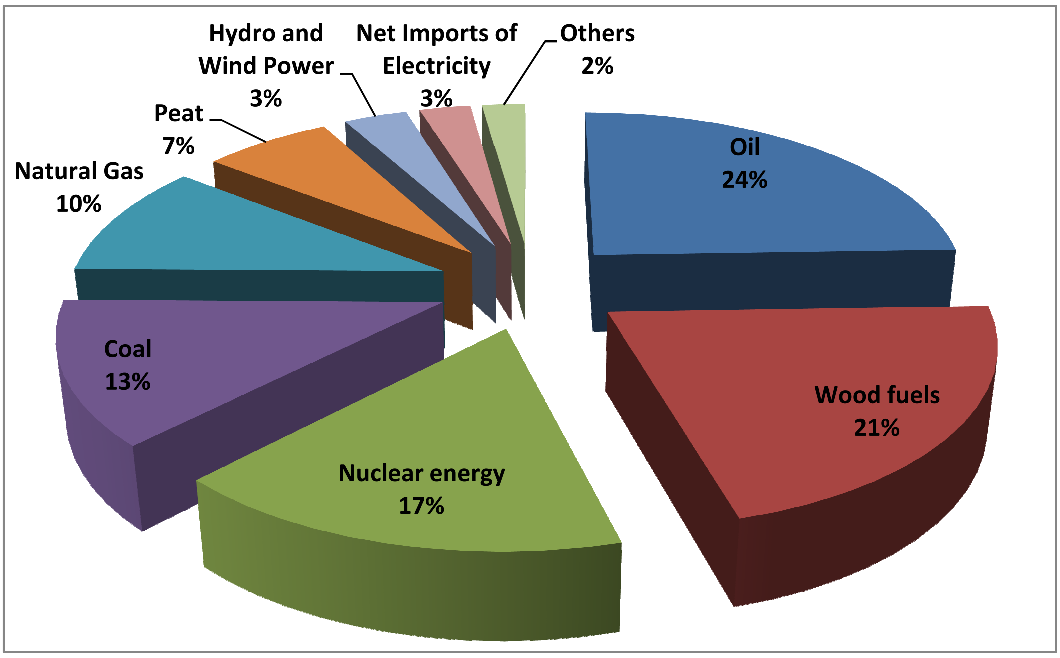


Figure 3.3.2. Total energy consumption by source – Finland 2010

As can be seen, the majority energy consumed come from non renewable energies. (Statistics: Energy supply, consumption and prices [e-publication], 2011)

3.3.2 Energies used in heating

District heating is the most common form of heating in Finland. It is a natural and reliable heating method in densely built areas. District heating has been produced in Finland since the early 1950s.

It is available in almost all towns and population centres. About 2.6 million Finns live in houses heated by district heat. District heating accounts for almost 50 per cent of the total heating market. The more densely built the area is and the larger the buildings, the more economical district heating is. Almost 95% of apartment buildings and most public and commercial buildings are connected to the district heating network. **In single-family houses, just over 6% of the heating energy comes from district heat**. In the largest towns, the market share of district heating is more than 90%.

The superior energy efficiency and environmental compatibility of district heating are based especially on the fact that district heating utilises heat energy generated in electricity production (combined heat and power generation), and waste heat from industrial and other processes, etc., which would otherwise be wasted.

District heating fuels include natural gas (was used to generate 35% of district heat and co-generated electricity), coal, peat, oil, and increasingly wood and other renewable energy sources, such as biogas. Almost 80% of district heating is obtained from heating plants producing heat and electricity (cogeneration), as surplus heat from industry or from biogas combustion in landfills. At small localities, these heat sources are often not available. In such a case, district heat is produced in heating plants producing heat only, often using wood and other renewable fuels.

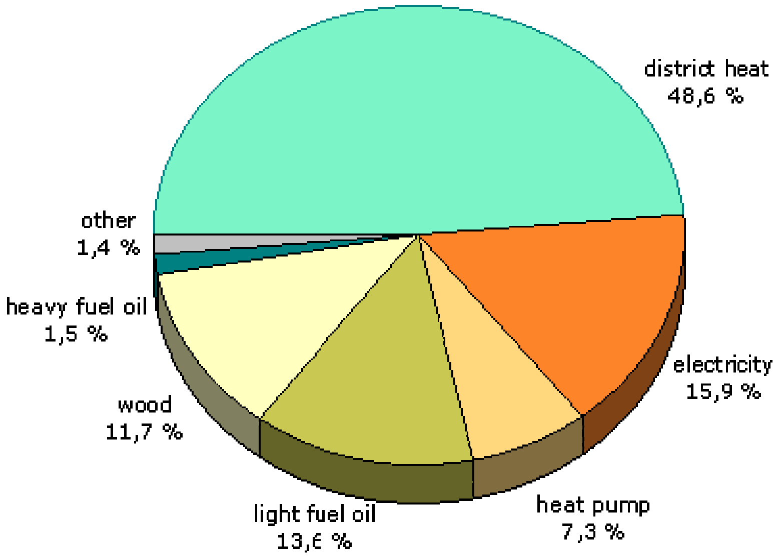


Figure 3.3.3 Market shares of heating buildings, year 2007.

(Statistics Finland)

Customers receive heat through the hot water circulating in the district heating network. The hot water in the supply pipe releases heat to the heating and hot service water networks of the house with the customer's heat exchanger. District heating water does not circulate in the heating and service water networks of the house.

(Energiateollisuus, 2011)

3.3.3 Finnish climate data

Before doing any calculation, the basic information that must be known about every country where a solar installation is going to be settled, is the climatologic situation, temperature, weather and solar irradiation.

A recompilation of monthly average values and extremes for the temperature during this period of time has been done. It is called "Tilastoja Suomen ilmastosta 1971-2000 - Climatological statistics of Finland 1971-2000".

Some of the tables included there show the monthly average values for pressure, precipitation, relative humidity and average of snow depth on the 15th and last day of the month. An example is shown in Table 3.3.1, where the information about Helsinki, the capital, is represented.

In this thesis a solar installation in Tampere is going to be analyzed. Then, it has to be considered that Tampere is in the north of Helsinki (60° 10`N 24° 56`E), in between Helsinki and Jyväskylä (62° 24`N 25° 40`E) which is in the middle of Finland. Figure IV.B.1, included in Appendix IV.B: Climatic data in Finland, illustrates the different regions in Finland, so that the reader could understand where Tampere is located: Helsinki is in the region of Uusimaa, Tampere is in Pirkanmaa, and Jyväskylä in Central Finland. Then, the temperature data in Tampere is more less an average between Helsinki and Jyväskylä, but closer to the last one, which data is shown in Table IV.B.1. This is because they both are inland cities and with similar climate.

Table 3.3.1. Different temperature values measured in Helsinki (1971-2000).

HELSINKI KAISANIEMI 1971-2000											
	Lämpötila °C Temperature °C					Lämpöt.päivät kpl/no T-days		SADE (mm) Precip.		LUMI (cm) Snow	
Kk Month	Keskimääräiset Mean	Max	Min	Abs. max	Abs. min	T max > 25°C	T min < 0°C	Keskim. Avg	Max per day	15.pvä 15 th	Viim. Last
1	-4,2	-1,7	-6,9	8,5	-34,3		26	47	85	14	20
2	-4,9	-2,2	-7,7	10,3	-26,0		24	36	101	23	24
3	-1,5	1,2	-4,2	11,5	-20,5		23	38	69	23	15
4	3,3	6,8	0,4	21,9	-10,5		13	36	113	0	
5	9,9	14,0	6,0	26,3	-3,1		1	32	68		
6	14,8	18,7	11,0	30,5	2,1	2		49	136		
7	17,2	20,9	13,7	30,8	7,1	3		62	136		
8	15,8	19,3	12,6	31,2	3,4	2		78	174		
9	10,9	13,9	8,1	24,1	-4,5		1	66	145		
10	6,2	8,6	3,8	17,4	-11,6		6	73	183		
11	1,4	3,6	-0,8	11,6	-18,6		15	68	160	1	3
12	-2,2	0,2	-5,0	12,6	-29,5		23	58	115	7	10
Vuosi Year	5,6	8,6	2,6	31,2	-34,3	7	132	642			

In addition to the temperature, the precipitation data is also important, as it interferes in the solar energy received. Figure 3.3.4 shows the mean annual temperature (°C) on the left and the average annual precipitation (mm) on the right.

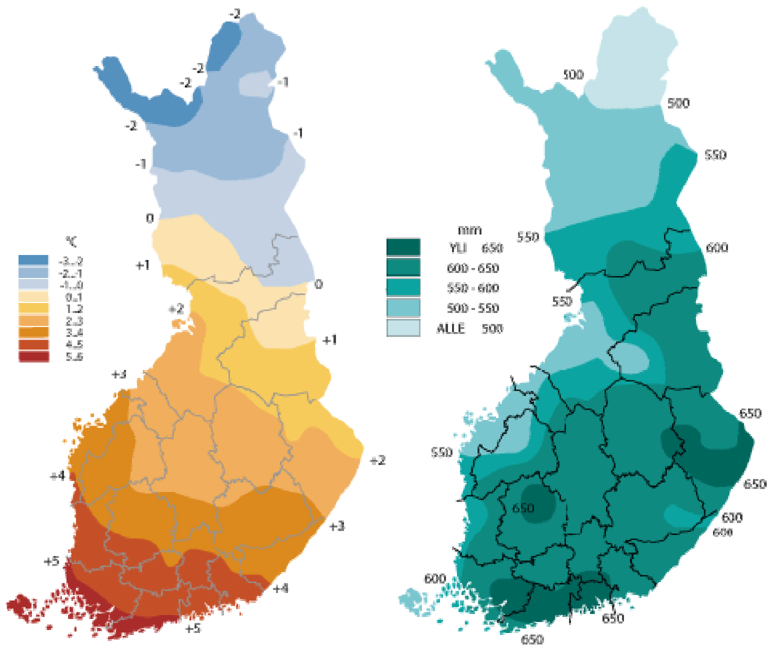


Figure 3.3.4. Mean annual temperature and precipitation in Finland.

Also, the wind data is important and should not be neglected, as it is one of the reasons for heat losses over solar collectors. The data about the wind distribution in Finland can be seen in Table IV.B.2.

Further, referring to the field of study of this thesis, the sun, it is important to mention that because of his geographical situation, Finland has plenty of sun hours in summer, but not in winter. This is well defined in Table IV.B.3.

The fact that this northern country has plenty of daylight hours is one of the reasons why Finland is now improving and setting more solar installations, to achieve the 20% of energy from renewable energies that the EU dictates (European Union, 2009).

(Finnish Meteorological Institute, 2011)

Furthermore, the really useful data for this thesis is not only the amount of light, but the solar energy that is received by a collector. Table 3.3.4. in the next subchapter shows the irradiation in the city of Tampere over a horizontal surface.

3.3.4 Finnish regulations

The document *Suomen rakentamismääräyskokoelma [Building Code of Finland]* gathers all the specifications that buildings and solar installations have to fulfil. In this thesis, not all the specifications are going to be mentioned[36], but only the ones that are important and refers to what is going to be studied.

Primary energy consumption allowance

About energy efficiency of buildings (section D3 of the building code) is important emphasize that there is a limitation about energy consumption.

Table 3.3.2. Maximum annual primary energy consumption allowance [kWh/m²].

Type of building		**Floor area, A_f [m²]**	**[kWh/m²] per year**
Single family houses	Detached	$A_f < 120$	204
		$120 < A_f < 150$	$372 - 1{,}4 \cdot A_f$
		$150 < A_f < 600$	$173 - 0{,}07 \cdot A_f$
		$A_f > 600$	130
	Log	$A_f < 120$	229
		$120 < A_f < 150$	$397 - 1{,}4 \cdot A_f$
		$150 < A_f < 600$	$198 - 0{,}07 \cdot A_f$
		$A_f > 600$	155
	Semi-detached		150
Multifamily houses			130
Offices			170
Commercial building			240
Educational and daycare centre building			170
Sports hall, excluding ice ring			170
Hospital			450

This energy limitation is shown in Table 3.3.2 and depends on the type of building and the heated floor area A_f [m²].

If in this thesis the overall energy consumption for space heating and DHW altogether would be studied, this allowed primary energy consumption must have be done.

Climatic zones

For designing solar installations, the climate zone where the installation is going to be placed must be determined. Figure 3.3.5 represents these zones.

[36] For further information, the Finnish building code is public information and is referenced in this thesis: (Rakennetun ympäristön osasto [Built Environment Division.], 2011). So any individual can consult it, the only problem is that this document is in Finnish.

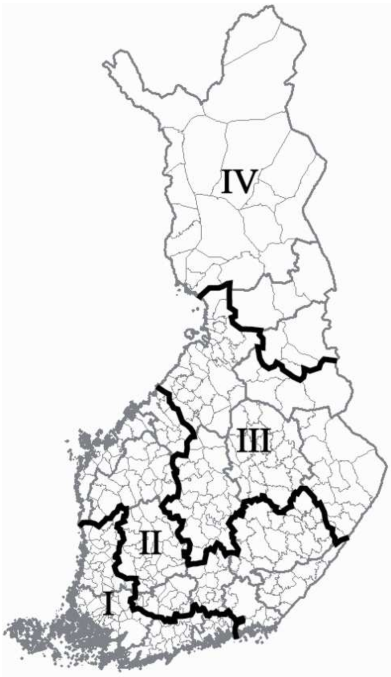


Figure 3.3.5. Climatic zones in Finland.

Then, for each zone, Table 3.3.3 shows the design and the average outside air temperatures.

Table 3.3.3. Design and average outdoor air temperatures for each climate zone.

Climatic zone	Design outdoor air temperature [ºC]	Average outdoor air temperature [ºC]
I	-26	5,4
II	-29	4,7
III	-32	3,3
IV	-38	-0,3

And about solar irradiation, the Finnish building code in the calculations section (section D5) shows the real data measured in zones I and II, represented in Table 3.3.4. Those zones are important because one of the houses object of study is going to be placed in Tampere, and therefore, in zone II.

This data will be compared with the one provided in the database of the software that is going to use for the analyses, to check the veracity of the calculations based on irradiation of the software.

Table 3.3.4. Weather data over a horizontal surface for climatic zones I and II.

Tampere	Average air temperature [ºC]	Total solar irradiation [kWh/m²]
January	-3,97	6,2
February	-4,50	22,4
March	-2,58	64,3
April	4,50	119,9
May	10,76	165,5
June	14,23	168,6
July	17,30	180,9
August	16,05	126,7
September	10,53	82,0
October	6,20	26,2
November	0,50	8,1
December	-2,19	4,4
YEAR	5,57	975,2

DHW reference demand

In addition, at his building code, there is a reference value for DWH consumption per day and person, which will be used in the calculations. This value is: 50l/person·day of water at 58ºC.

(Rakennetun ympäristön osasto [Built Environment Division.], 2011)

3.4 Spanish situation

According to the European directives, as well as Finland, Spain has updated its regulations for fulfilling the requirements of the EU. Also, an action plan has been done: *Plan de Acción Nacional de Energías Renovables de España (PANER) 2011 – 2020* [National Action Plan of Renewable Energies 2011 - 2020]. This is the last one; the previous was prepared for the period 2005 – 2010.

In this chapter are going to be studied the energetic situation in Spain, the use of renewable energies, the climate conditions for facing solar energy installations and the regulations related with this subject.

3.4.1 Renewable energies in Spain

The current energetic situation in Spain is going to be studied in this chapter. The data provided by *Instituto para la Diversificacion y Ahorro de la Energía (IDAE*) [Institute for Diversification and Saving of Energy] and *Ministerio de Industria, Turismo y Comercio (MICyT)* [Ministry of Industry, Tourism and Commerce] is similar to the one retrieved from IEA & OECD; so this last one will be used, as it is provided in English.

The evolution of the primary energy supply, from 1972 till 2088, can be seen in Figure V.B.5 (inside Appendix V.B: Energy statistics in EU, section *Energy statistics in Spain*). Since 1996 there has been an increasing until 2007, where there a decreasing of the energy. Also is important to mention the appearance of geothermal / solar / wind energy from 2000, increasing till nowadays. Figure 3.4.1 illustrates the share of the primary energy supply for 2008, which is the most actual data that the official sources provide publicly.

In this graph can be seen that, on the contrary of the Finnish case, the main primary energy supplied is from fossil fuels, 71,6% from which 46,6% is from oil and 25% from Gas.

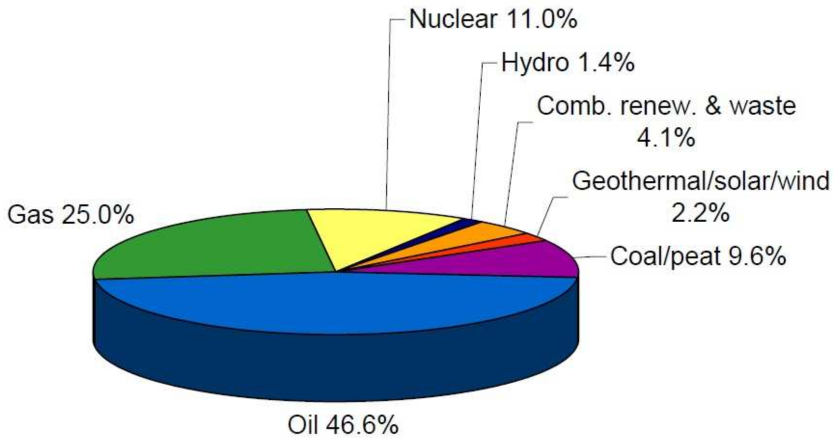


Figure 3.4.1. Share of total primary energy supply in Spain in 2008.

About the evolution of the energy production in the country, as Figure V.B.6. represents, since 1983 there has been a decrease in coal / peat and oil; since 1990 an increase of renewable and waste; and since 1999 geothermal / solar / wind production has been increasing till 2008. Related to this, Figure V.B.7 demonstrates the evolution of the electricity generation by fuel. There can be seen the increase of electricity generated by gas since 1996 and, more important because they are renewable sources, a notable increase since 2000 of the generated by geothermal / solar / wind and a combination of renewable and waste (this one slightly).

However, the matter that is more important for this thesis is the energy consumption. Figure V.B.8 illustrates the evolution of the final consumption by sector. The remarkable thing about this graph is that there has been a continuous increasing till 2007, where a decreasing starts, as happened for the primary energy supply.

But, according to the European directive about the share of energy from renewable sources in the transport sector, which must amount to at least 10% of final energy consumption in the sector by 2020, is important to have a look the breakdown of sector final consumption by source (Figure V.B.9). As can be seen, in Transport sector, almost the total of energy consumption comes from oil. This is an issue that the Spanish government should take care of for achieving the European goal by 2020.

(IEA/OECD, 2011)

Currently, according to IDAE, the primary energy consumption is illustrated in Figure 3.4.2; renewable energies represent 9% of the total consumption.

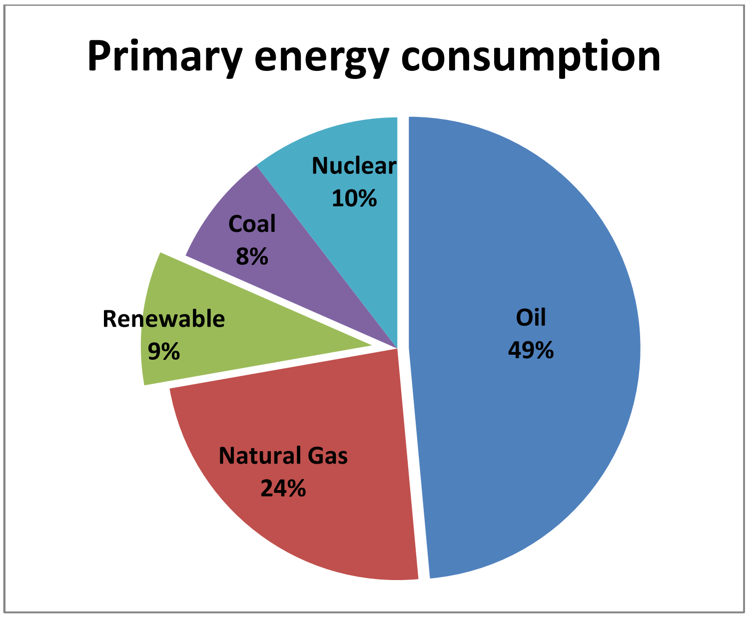


Figure 3.4.2. Primary energy consumption in 2009 in Spain.

From this percentage of renewable energies, in Figure 3.4.3 is shown the composition of this consumption; being the majority from biomass and waste with 41% and solar energy, object of this thesis, just a 5%.

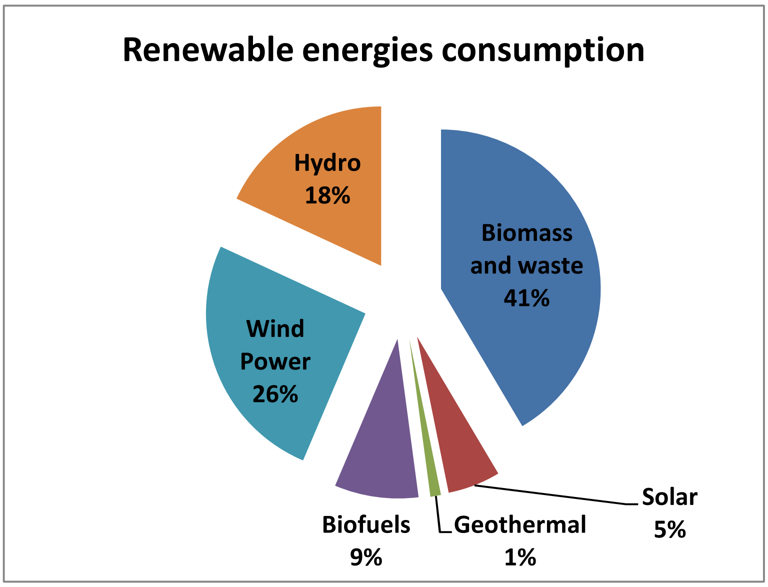


Figure 3.4.3. Renewable energies distribution in 2009 in Spain.

(IDAE, 2009)

3.4.2 Spanish climate data

Before performing any study about solar energy, a climatologic background of the area where the analysis is going to be done is necessary.

The *AEMET (Agencia Estatal de Meteorología)* [National Meteorological Agency] compiles every year an annual climatological summary. From there, the basic climate information has been retrieved.

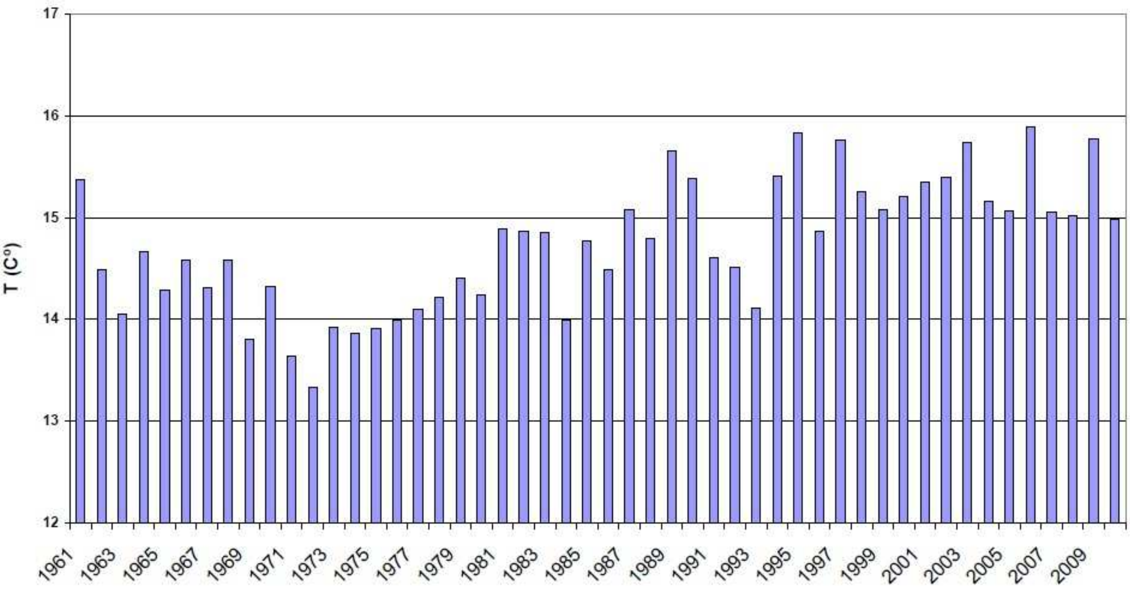


Figure 3.4.4. Evolution of the average annual temperature in Spain.

First of all, the main difference between Finish and Spanish climate is the average temperature; Figure 3.4.4 shows the average annual temperature in Spain since 1961. And for this past year, 2010, the behavior of the temperature in Spain is represented in Figure 3.4.5.

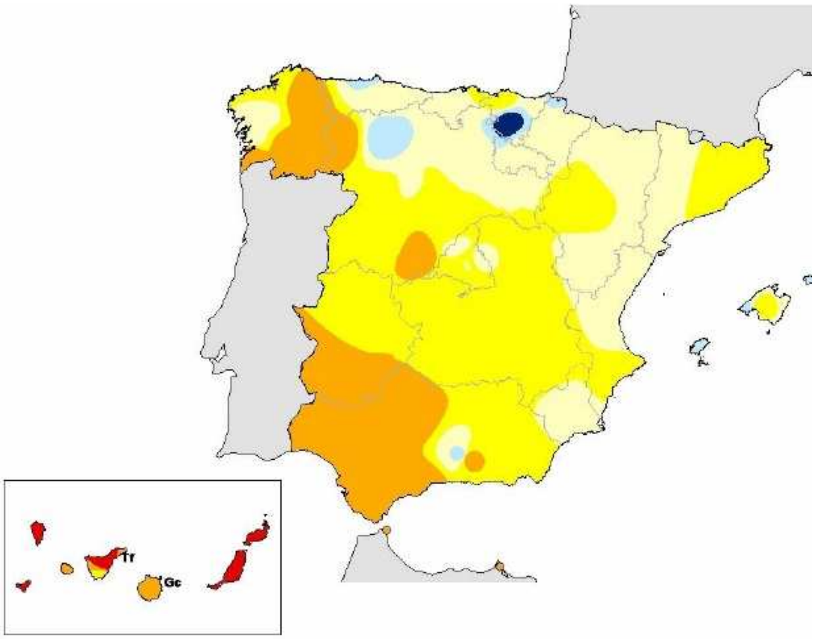


Figure 3.4.5. Temperature behaviour in Spain compared to the average.

But not only is the temperature the most important aspect, the precipitations must be considered as well as the cloudiness. As can be seen in Figure 3.4.6, the percentage of precipitations varies from 50% to 300%, compared with the average value, depending on the region.

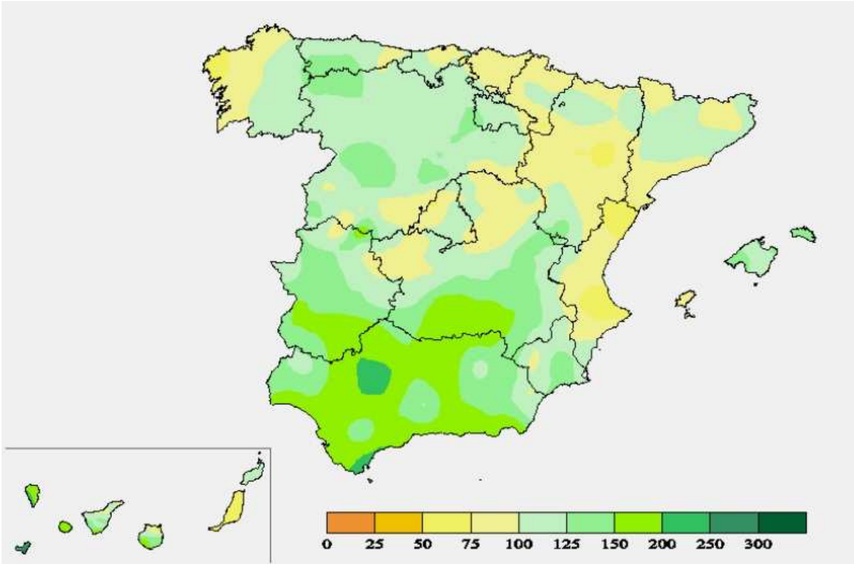


Figure 3.4.6. Percentage of precipitation during 2010, compared with the normal value.

Focusing in the matter of this thesis, the amount of solar hours and solar energy received is the main difference between Finland and Spain. Figure 3.4.7 represents the percentage of sun hours during 2010 compared to the average value; there can be seen that the sun hours have decreased comparing to the usual.

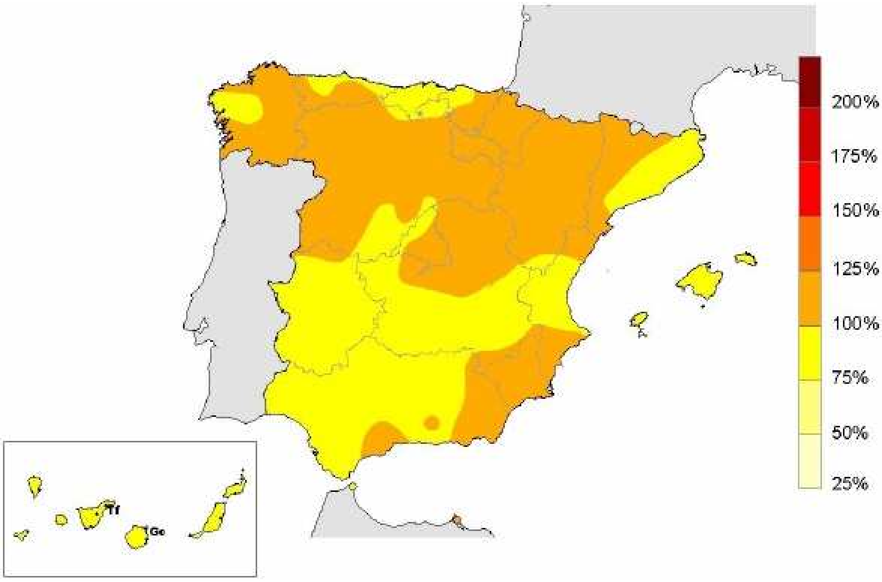


Figure 3.4.7. Percentage of sun hours in 2010 compared with the average value.

As the Spanish city object of study is Madrid, Table IV.C.4 must be consulted to have a general idea about which are the standard climate values for this city.

(AEMET, 2010)

About the irradiance, Figure IV.C.2 and Figure IV.C.3 represent the annual global irradiance and the beam radiation in Spain, respectively.

For further information about water temperature, outdoor temperature, geographical data and, last but not least, irradiance data for local purposes (for specific cities in Spain), Tables IV.C.1 to 4 should be checked.

3.4.3 Spanish regulations

Based on the EU directives, Spain has updated its regulations for fulfilling the requirements of the EU. The main documents that are going to be used for the analysis of this thesis are

- *CTE. (2009, 04). Código Técnico de Edificación - Documento Básico HE: Ahorro de Energía* [Technical Building Code - Basic Document HE: Energy Savings]
- *Reglamento de Instalaciones Térmicas en los Edificios (RITE)* [Regulations of Thermal Installations in Buildings] *y sus Instrucciones Técnicas* [and its Technical Instructions].
- And from IDAE: *Pliego de Condiciones Técnicas de Insatalaciones de Baja Temperatura* [Technical conditions for low temperature installations]. It is a compilation of the regulations from CTE HE and RITE (the two previous documents)

The main regulations and restrictions, useful for this thesis, are explained below. For further information, the regulations can be found referred in this thesis, and as it is public information, it can be found online on the official websites.

No direct systems

For DHW applications, direct systems are forbidden. And for other applications, neither direct systems are allowed to be installed in zone where freezing risk is present.

About the DWH systems dimensioning characteristics, it is said:

Total collector area

Another restriction existing in the Spanish regulations says that Total collector area, A_{Tc} [m^2], must be so that the Equation 3.4-1 is fulfilled.

$$50 < \frac{C_s}{A_{Tc}} < 180$$

Equation 3.4-1

Where V_s is the volume of the storage device [l] and its recommended value is that it must be approximately equal to the daily DHW demand. An initial value of 75 l/m² will be used for starting the study.

Also, for installations with low solar fraction values, it must be considered a low V/A ratio; and for installations with higher solar fraction values, this ratio must be increased.

DHW reference demand

In the Spanish Basic Document for Energy Savings (CTE, 2009) are listed the reference demand values, for a water temperature of 60 ºC, depending on the type of building. Table 3.4.1 illustrates this data, where, has been subtracted that for single family house, the DHW demand at 60 ºC is 30 litres/person·day.

Table 3.4.1. DHW demand at 60 ºC depending on the use of the building.

Demand criteria	DHW l/day at 60 ºC	
Single family house dwelling	30	per person
Multifamily house dwelling	22	per person
Hospital	55	per bed
Hotel ****	70	per bed
Hotel ***	55	per bed
Hotel **	40	per bed
Camping	40	per parcel
Hostel / Hotel *	35	per bed
Dormitory / Old people's home	55	per bed
Dressing room / Colective showers	15	per unit
Schools	3	per pupil
Barracks	20	per person
Factories	15	per person
Administrative	3	per person
Gymnasium	20-25	per user
Laundry	3-5	per kg clothes
Restaurant	5-10	per lunch
Café	1	per meal

If the demand DHW temperature is not 60 ºC, CTE HE provides a formula for obtaining the reference demand at different temperatures. It is shown in Equation 3.4-2.

$$D(T) = \sum_{i=1}^{12} D_i(T)$$

Equation 3.4-2

Where *D(T)* is the annual DHW demand at chosen temperature *T*, and $D_i(T)$ is the monthly DHW demand at *T*, expressed in Equation 3.4-3.

$$D_i(T) = D(T = 60ºC) \cdot \left(\frac{60 - T_i}{T - T_i}\right)$$

Equation 3.4-3

Where *D(T = 60 ºC)* is the demand at 60 ºC, and T_i is the average water temperature from the network, for the month *i*. Table IV.C.2 represents the water temperature in the main cities in Spain.

Solar fraction

The month solar fraction of the installation must never surpass the value of 110% of the DHW demand, and during no more than three consecutive months this value must never be more than 100%. Also, for some specific seasonal installations, will not be considered the periods of time in which the demand is under 50% of the average yearly demand.

In addition to this maximum monthly percentage allowed, there is a condition that must be fulfilled: a minimum of solar contribution for the installation. This minimum depends on the total DHW demand in the building, and the climatic zone where the building is placed. Table 3.4.2. represents this minimum solar fraction and Figure IV.C.1 shows the Spanish climatic zones.

Table 3.4.2. Minimum solar contribution for a building.

Total DHW demand in the building (l/d)	Climatic zone				
	I	II	III	IV	V
50-5.000	30	30	50	60	70
5.000-6.000	30	30	55	65	70
6.000-7.000	30	35	61	70	70
7.000-8.000	30	45	63	70	70
8.000-9.000	30	52	65	70	70
9.000-10.000	30	55	70	70	70
10.000-12.500	30	65	70	70	70
12.500-15.000	30	70	70	70	70
15.000-17.500	35	70	70	70	70
17.500-20.000	45	70	70	70	70
> 20.000	52	70	70	70	70

Legionella prevention

The solar thermal system must be able to increase the storage temperature to 60ºC and also till 70ºC with the aim of avoiding legionellosis, as expressed in the regulation *RD 865/2003 from the 4th July 2003.*

For DHW applications a punctual connection is needed between the auxiliary energy system and the solar system; so this way this last one can be heated by the auxiliary energy source, with the aim of fulfilling the preventions measurement of legionella.

(CTE, 2009) & (IDAE, 2009)

4 Analysis

The main objective of this thesis is to compare a single family house, with identical characteristics, in two different climatologic situations. For that, the first part of analyzing is to determine the house model that is going to be studied in both countries.

Secondly, the non-renewable heating needed for this house is going to be dimensioned with the software RETScreen, which will represent the current situation of a single family house. Also, at the beginning of the simulations, before performing any study, a verification of the climate data provided for the software will be done.

Afterwards, the study of a thermal solar installation, based on RETScreen as well, is going to be done; aimed for DHW, nor space heating. For that, at the beginning, an analysis about how much energy will be needed for heating the DHW demanded in each country will be performed. Then, in the solar installation analysis indeed, the situation with different types of collectors and with different collector surface area will be analyzed, to determine which solution is better for each country.

And at the end, an economical analysis will be performed. In it, the allowed investment for each case will be studied.

4.1 Geographical and physical situation

Before starting any study, the location and orientation of the virtual houses must be defined, as well as the surroundings.

- The virtual house is going to be placed in:
  - Finnish case: in the city of Tampere, whose coordinates are 61°29′53″N and 23°45′39″ E. It is the second largest city in Finland, and is in the north of Helsinki, the capital of Finland.
  - Spanish case: in the city of Madrid, whose coordinates are 40°40′00″N 03°70′00″ W. It is the capital, and is situated in the middle of the country.
- Climatic data: the verification about RETScreen database, if is trustful and shows the reality, is the initial part of the analysis. The results of this verification are shown in Chapter 5.
- Both group of collector will be heading south, with no building or obstacles (i.e. tress) producing shadow over their surface.
- The collectors will be non tracking and with fixed tilt. As it is explained in Chapter 2.2.4.1, the optimal tilt angle, β_{opt}, for receiving the maximum amount of direct beam radiation, depends on the period of use of the solar installation:
  - Constant annual consumption: tilting must be equal to the latitude, $\beta = \varphi$.
  - Preferential winter consumption: tilting should be the latitude increased in 10°, $\beta = \varphi + 10°$.

- Preferential summer consumption: tilting should be the latitude decreased in 10°, $\beta = \varphi - 10º$.

Then, the first approach of setting both groups of collectors is going to be made considering constant annual consumption. Consequently, the tilting angles of the collects in each country are:

  - Finnish case: $\beta = \varphi_{\ Tampere} = 61°$.
  - Spanish case: $\beta = \varphi_{\ Madrid} = 40°$.

However, as a part of the analysis, the variation of the tilting angle will be done, looking for the real optimum slope, β_{opt}, with which more annual radiation will be received.

4.2 House model

The type of house object of study in this thesis is a single family house. This house is going to be virtually placed in each country, and is going to have the same characteristics: same dimensions, orientation and number of occupants.

For this study to be reasonable, this virtual house that is analyzed must be as close to reality as possible. Hence, for designing the house, the number of occupants and the surface of the house must be determined. For that, statistic European data is going to be used, whose sources are: Eurostat[37] (European Comissoin, 2011) and the document *Housing Statistics in the European Union 2010* (Dol & Haffner, September 2010). The important data is attached as tables at Appendix V.A: Housing Statistics in the European Union.

4.2.1 Number of occupants

First of all, it has to be determined how many persons live in the virtual house that is going to be compared in both countries. For this reason, a research about the house size has been done. In Table V.A.1, inside Appendix V.A, is shown the percentage distribution of different house sizes corresponding to the years 1981, 2004 and 2008, for some European countries.

Thus, the data from Finland and Spain in 2008 has been subtracted for being studied, as it is the nearest data to the present year, 2011, that has been found. Figure 4.2.1 represents the proportion between different sizes of dwellings[38]: 1 person, 2 persons, 3 persons, 4 persons, and 5 or more persons; in both countries. There it can be seen that in Finland the most common dwelling is the 1 person house, while in Spain is the 2 person size house.

[37] Eurostat: (Mathematics & Measurements / Statistics) an organization within the European Union that collects and collates statistical information relating to member states. Full name Statistical Office of the European Communities (Collins English Dictionary, 2003).

[38] Dwelling: the definition varies depending on the country. (See Appendix I. Terms and Definitions)

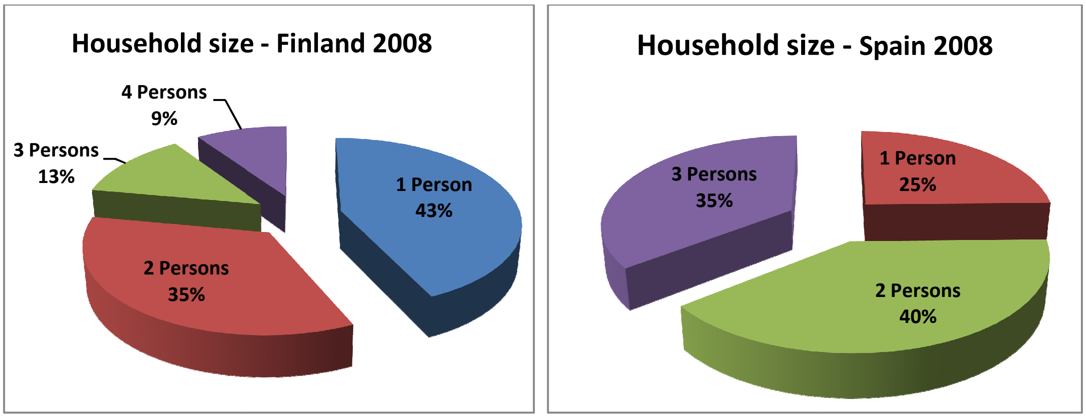


Figure 4.2.1. Household size percentage in Finland and Spain at 2008.

However, this data is not representative for the case that is wanted to be studied, the one family house, as multifamily houses are included (i.e. block of flats); and this multifamily house represents a big percentage of all the dwellings, as can be seen in Figure 4.2.2 (Data retrieved from Table V.A.2).

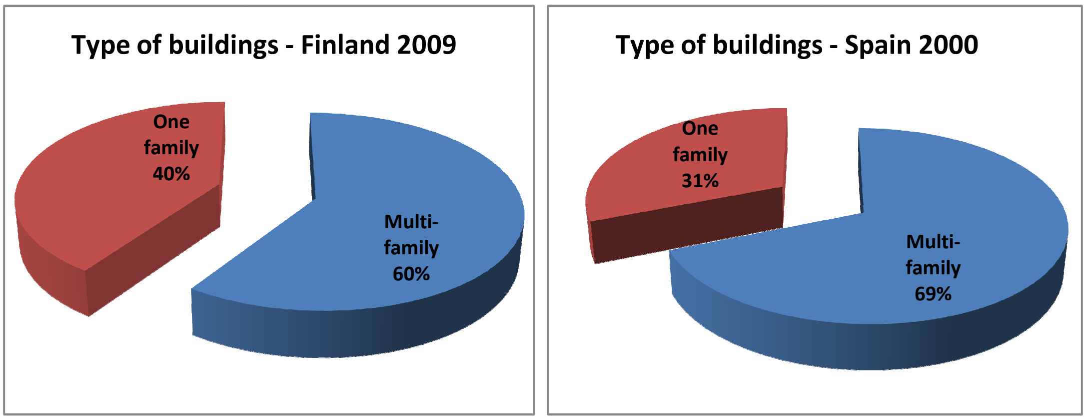


Figure 4.2.2. Dwelling stock by type of building.

The reason that the year in the graph about Finland is closer than 2011 and the one in Spain it is not, is because there is no data for Spain referred to subsequent years, but the proportion would be more less the same nowadays.

Then, as one family houses are not the majority, it is needed another approach to determine the number of inhabitants that live in a house. Therefore, focusing on the density of people per dwelling is possible to estimate the average value of persons that live in a standard single family house. Figure 4.2.3 illustrates the average number of persons per household (data provided by Table V.A.3).

As can there be seen, the average in both countries is more than two residents by house. It must be commented that the absence of data from Spain referred to year 2009 is not because of an error, but of a lack of data in this year.

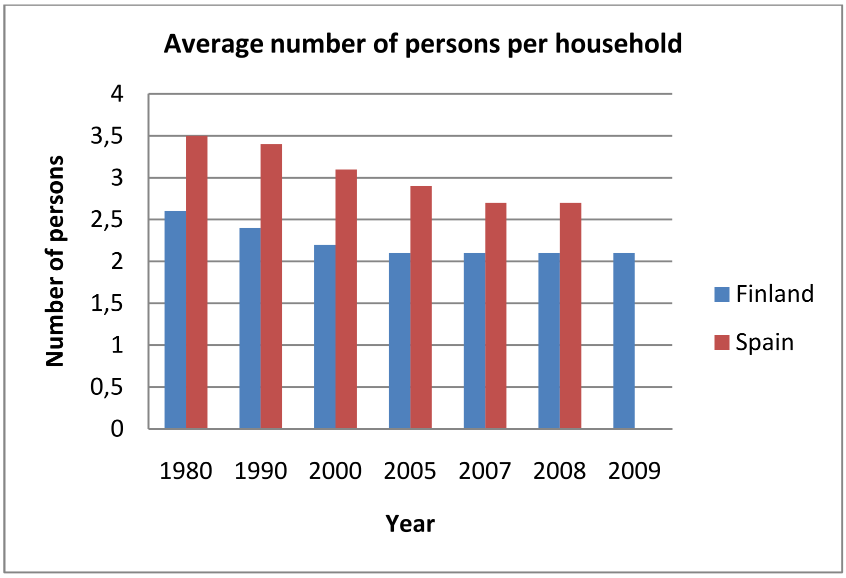


Figure 4.2.3. Evolution of the average number of persons per household.

However, these values are still not representative enough, because in them are represented unoccupied dwellings and second houses (as holiday residents). Thus, the data that is closer to reality is shown in Figure 4.2.4, which demonstrates the average number of persons per occupied dwelling (data obtained from Table V.A.4).

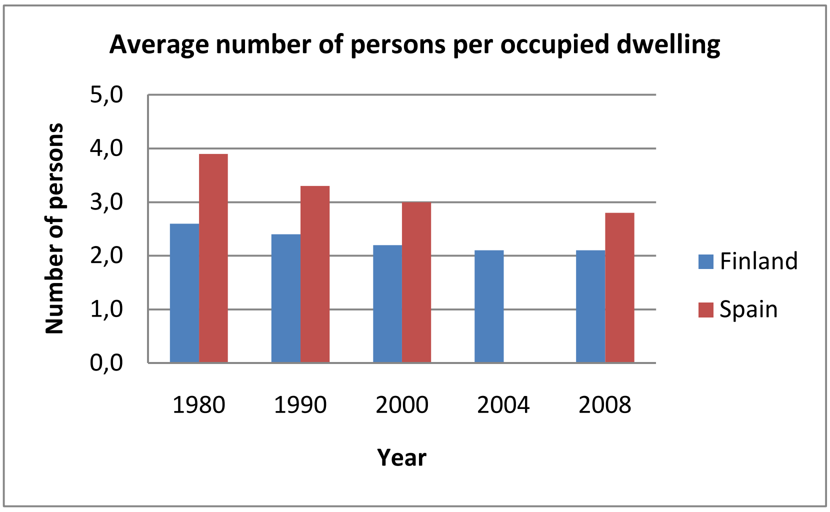


Figure 4.2.4. Evolution of the average number of persons per occupied dwelling.

In this case, the situation in Finland behaves the same way, with the same values. But in the other hand, the number of inhabitants in Spain has increased significantly, and is almost three (again, there is a lack of data, from the year 2004). The reason why this difference between occupied and unoccupied houses exists could be because Spain is a common destination for holidays, national and international tourism, and then those vacation dwellings are most of the time unoccupied.

All in all, a good approach has been achieved, as it has been tried to distinguish between multifamily and single family houses, and then, to reach the more accurate value for a standard primary residency, avoiding unoccupied houses.

In conclusion, the number of inhabitants for the virtual house that is going to be studied is **three**.

4.2.2 Dimension: Floor area

Once the average number of persons living in the house is known, it has to be obtained the average area of the virtual house that is going to be studied.

One possible approach is analyzing the number of rooms that the house is going to have. The more rooms there are, the bigger would the house be. Table 4.2.1 represents the average number of total dwellings (completed and projected) and completed ones (data provided from Table V.A.5). There can be seen that Spanish houses has more rooms than Finnish.

Table 4.2.1. Average number of rooms per dwelling stock and already completed.

	Total dwelling stock	Year	Dwellings completed	Year
Finland	3,7	2009	4,2	2009
Spain	5,1	2008	6,0	2003

Despite the number of rooms, this conclusion could not be accurate; as, for example, it could happens that even if Finnish houses have less rooms, each room could have bigger surface than Spanish ones. Due to this possibility, it is needed to look for another statistical value that could lead to estimate the average surface of the virtual house.

For this reason the useful floor area[39] of the dwelling is going to be analyzed. Table 4.2.2 shows the average useful floor area per dwelling and per person (data obtained from Table V.E)

Table 4.2.2. Average useful floor area per dwelling and per person (m^2)

	Finland (2009)	Spain (2008)	Units
Total dwelling stock	79,4	99,1	(m2/dwelling)
Dwellings completed	101,7	116,0	(m2/dwelling)
Dwellings completed	38,9	33,0	(m2/person)

After studying this data, two possible decisions can be made: either choosing by the area of the dwelling, or either using the number of inhabitants per dwelling. About which total value to choose, if the total dwelling stock (first row) or the dwellings completed (second row), it has been decided to use the dwellings completed. This is because as this thesis consists in improving a non-renewable heating system by adding a thermal solar installation, it is supposed that the house must be already constructed, and therefore, completed.

- Case 1: (m^2/dwelling)

The value obtained from this approach will be the average between the Finish and Spanish house area:

$$\bar{S} = \frac{101{,}7 + 116{,}0}{2} = 108{,}85m^2$$

Equation 4.2-1

- Case 2: (m^2/person)

As the number of inhabitants has been obtained, three, then the surface will be the average between the Finish and Spanish situation:

[39] Useful floor area: the definition varies slightly in each country. (See Appendix I. Terms and Definitions)

$$\bar{S} = \frac{(38{,}9 + 33) \cdot 3}{2} = 107{,}85 m^2$$

Equation 4.2-2

As a result, as both cases are very similar, the final surface of the house object of study is going to be the approximate value**: S = 110 m^2**.

(Dol & Haffner, September 2010)

4.3 Software analysis

All the analysis, the first non-renewable for knowing the existing heating method and the one with the solar installation, are going to be performed with the software RETScreen (Natural Resources Canada, 2010). It is a free-of-charge Clean Energy Project Analysis Software. With which can be evaluated: the energy production and savings, costs, emission reductions, financial viability and risk for various types of Renewable-energy and Energy-efficient Technologies (RETs).

These analyses are going to be held similarly for both countries, where the difference between them is going to be the climate condition. Therefore the power needed to heat the house will be different in Spain that in Finland.

Secondly, after the non renewable analysis, the renewable solution will be studied. In this solution are going to be considered different types of collector, as well as different collector areas.

4.3.1 Climate data

The first thing that will be studied, before any software analysis, is going to be the veracity of the climate database from RETScreen. For that, official data from both countries will be compared with the ones provided by the software.

4.3.2 Non renewable analysis

First of all, before studying the solar thermal installation, the current virtual heating system must be dimensioned. And therefore, this situation is the one that is going to be improved with the solar heating installation.

The difference between both heating systems is that in Finland, as the climate is colder, the power needed to heat the house and for DHW is going to be bigger than in Spain. This is the reason why this heating situation must be analyzed separately.

Some characteristics are going to be the same for both analysis, but some does not; these ones are going to be explained for each country. The specifications for the simulation are:

Project information

- **Heating** project.
- **Boiler** technology.
- **Lower Heating Value** (LHV)

  Heating Value is a measure of energy released when a fuel is completely burned. Depending on the composition of the fuel (amount of hydrogen) the amount of steam in the combustion products varies. Higher heating value (HHV) is calculated assuming the combustion product is condensed and the steam is converted to water. Lower heating value (LHV) is calculated assuming the combustion product stays in a vapour form. Higher heating value is typically used in Canada and USA, while lower heating value is used in the rest of the world.

Site reference conditions

- **Finland**

Table 4.3.1 represents the climate data location provided by RETScreen about Tampere/Pirkkala.

Table 4.3.1. Climate data location for Tampere/Pirkkala.

	Unit	Climate data location	Project location
Latitude	˚N	61,3	61,3
Longitude	˚E	23,6	23,5
Elevation	m	112	112
Heating design temperature	°C	-21,8	
Cooling design temperature	°C	24,9	
Earth temperature amplitude	°C	19,9	

This information was taken in a 61,4º latitude and 23,6º longitude, very close to our project location. In RETScreen the project location is changed from 61,4º to 61,3º, and 26,6º to 23,5º, where the house is going to be located.

Also, as there can be seen, the heating design temperature is -21,8 ºC. However, in Finnish regulations for Energy efficiency of Buildings, section D5 (Rakennetun ympäristön osasto [Built Environment Division.], 2011) it is expressed a specific design temperature (explained at Chapter 3.3.3 Finnish climate data). As Tampere is inside the Climatic zone II (see Figure 3.3.5), then the heating design temperature is -29 ºC (data subtracted from Table 3.3.3).

Table 4.3.2. Climate data location for the Finnish project.

	Unit	Climate data location	Project location
Latitude	˚N	61,3	61,4
Longitude	˚E	23,6	23,5
Elevation	m	112	112
Heating design temperature	°C	-29,0	
Cooling design temperature	°C	24,9	
Earth temperature amplitude	°C	19,9	

Hence, the new climate data location for this project is represented in Table 4.3.2. The overall climate data, provided by RETScreen database, of Tampere can be seen in Table VI.1 (in Appendix VI. Tables and figures from RETScreen).

- **Madrid**

Table 4.3.4 represents the climate data location provided by RETScreen about Madrid.

Table 4.3.3. Climate data location for Madrid.

	Unit	Climate data location	Project location
Latitude	˚N	40,4	40,4
Longitude	˚E	-3,7	-3,7
Elevation	m	667	667
Heating design temperature	°C	-2,8	
Cooling design temperature	°C	34,9	
Earth temperature amplitude	°C	23,6	

However, the heating design temperature, which represents the minimum temperature that has been measured, must be modified. Because, according to Table 4.3.4 (data provided from Table IV.C.1, in Appendix IV.C) the real data, the minimum historical temperature registered is -16 ºC.

Table 4.3.4. Geographical data of Madrid

Madrid	Value	Units
Latitude	40,4	ºN
Longitude	3,7	ºW
Elevation	667	m
Historical minimum temperature	-16	ºC

The latitude, longitude and elevation do not need to be modified. Thus, the final and updated data, for the geographical situation of the house in Spain is shown in Table 4.3.5.

Table 4.3.5. Climate data location for the Spanish project.

	Unit	Climate data location	Project location
Latitude	˚N	40,4	40,4
Longitude	˚E	-3,7	-3,7
Elevation	m	667	667
Heating design temperature	°C	-16,0	
Cooling design temperature	°C	34,9	
Earth temperature amplitude	°C	23,6	

The overall climate data, provided by RETScreen database, of Madrid can be seen in Table VI.2.

Energy model

- Heated floor area for building: **110 m^2** (as analyzed in the previous chapter)
- Heating load for building:

Depends on the design temperature, which is the most unfavourable case (i.e. the coldest day in winter), and the insulation level. Residential built before 1970 will generally have "Low" insulation levels unless improvements have been made to the building envelope. Houses built between 1970 and 1990 usually have "Medium" insulation levels whereas those built after 1990 will have "High" insulation levels. Hence, for this case, a **Medium insulation level** will be chosen.

- **Finland**

The heating load value is obtained from Figure 4.3.1, entering in the graph with -29 ºC as heating design temperature, with a medium insulation level.

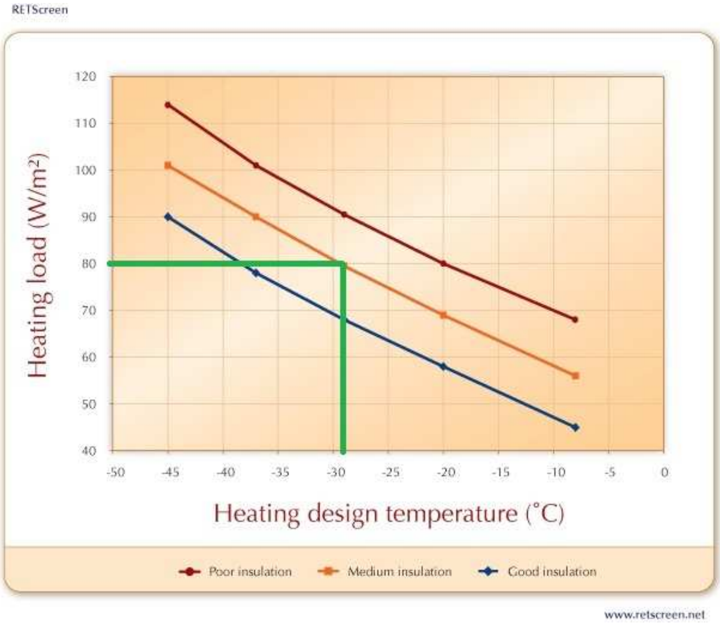


Figure 4.3.1. Building Heating Load chart for the house in Tampere.

As a result, the heating load for building is **80 W/m^2**.

With all this information, the program can calculate the total needed energy for heating and HDW. This result is shown in Chapter 5.2: Non renewable analysis results.

- **Madrid**

The heating load value is obtained from Figure 4.3.2, entering in the graph with -16 ºC as heating design temperature, with a medium insulation level.

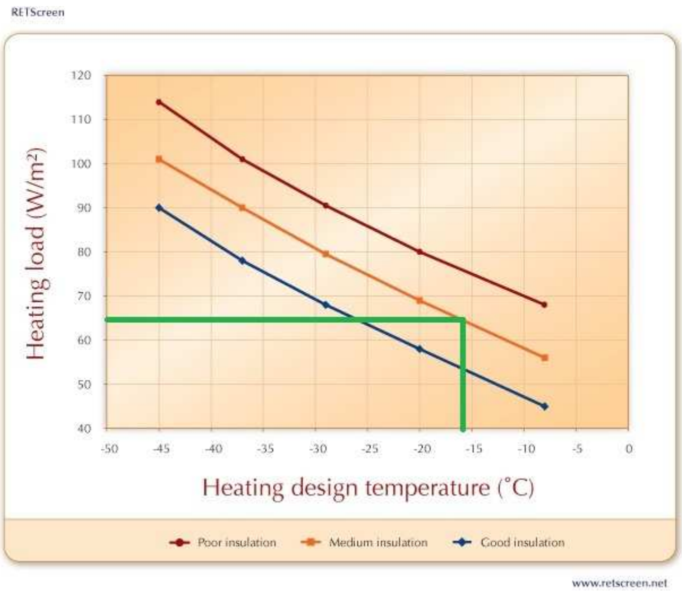


Figure 4.3.2. Building Heating Load chart for the house in Madrid.

As a result, the heating load for building is 65 W/m2.

With all this information, the program can calculate the total needed energy for heating and DHW, which is shown in Chapter 5.2. Non renewable analysis results.

- Domestic hot water heating base demand: **25%**

Is an estimated DHW heating base demand as a percentage of the total heating needs. In cold climates, typical values for domestic hot water heating base demand range from 0 to 25%. Then, for being in the conservative side, the maximum will be chosen for both cases.

- Fuel type: **Electricity**

An electric boiler is going to be used as heating system, despite the fact that in Spain, from all the houses that have heating system (70,3%), the majority (32,3%) use Natural gas as fuel, by individual heater or central heating, meanwhile the 18,6% of the dwellings use electric heating (INE Instituto Nacional de Estadística [National Statistic Institute], 2009).

This is because in Finland, even if the statistics indicates that district heating is the largest heating system (48,6%), in the case of single-family houses just over 6% of the heating energy comes from district heat. And therefore, the second source of energy for heating is electricity (15,9%), as can be seen in Figure 4.3.3 (Energiateollisuus, 2011). This means that for single family houses, the most common source of energy for heating is electricity.

Hence, in this thesis has been decided to have an electrical boiler for both cases. This way, both virtual houses have the same characteristics and therefore can be compared in a more objective way.

- Seasonal efficiency: **100%**

This value is generally lower than the steady-state efficiency because it is calculated on a seasonal basis. In other words, the "steady-state efficiency" is for full load conditions while the "seasonal efficiency" takes into consideration the lower efficiency part load conditions that occur during the year. Typical values for seasonal efficiency for heating systems range from 50% for a standard boiler or furnace (with pilot light) to 350% for a ground-source heat pump. Typical values of heating system efficiency are presented in Table 4.3.6. The first 3 listed are based on HHV natural gas fuel.

Table 4.3.6. Typical seasonal efficiencies of heating systems.

RETScreen

Heating system type	Typical annual heating system seasonal efficiency
Standard boiler/furnace (with pilot light)	55 to 65%
Mid efficiency boiler/furnace (spark ignition)	65 to 75%
High efficiency or condensing boiler/furnace	75 to 85%
Electric resistance	100%
Heat pump - air-source	130 to 200%
Heat pump - ground source	250 to 350%

www.retscreen.net

Thus, an electric resistance heating system type will be chosen, with a seasonal efficiency of 100%.

(Natural Resources Canada, 2010)

The results of the energy consumption for each house is listed and explained in Chapter 5: Results.

4.3.3 Analysis of the heating needs for DHW

Now that the heating consumption of these houses is calculated, the analysis of installing a solar thermal installation can be done.

However, first of all, the power needed to heat the water destined for DHW consumption must be determined. This is the previous analysis that will be done before the study of slope, type and area variation of the collectors.

Project information

- **Heating** project.
- **Solar water heater** technology.
- **Lower Heating Value** (LHV)

Site reference conditions

They are going to be the same as simulated before in the non renewable analysis, with the same data, for Tampere and for Madrid.

Energy model

Load characteristics

- Application: **Hot water**.
- Load type: **House.**
- Number of occupants: **3**.
- Occupancy rate: **100%**, as it is a dwelling.
- Hot Water Temperature: **60 ºC**.

  The data about domestic hot water consumption per person per day in each country, according to their regulations is:

  - **Finland:** 50 litres/person·day at 58ºC. (Rakennetun ympäristön osasto [Built Environment Division.], 2011).
  - **Spain:** 30 litres/person·day at 60ºC. (CTE, 2009).

  For making this analysis the more objective possible, a value of 60 ºC in both countries will be considered, as the Finnish temperature, 58ºC, can be approximated to 60 ºC.

- Daily hot water use:
  - **Finland: 50** litres/person·day.
  - **Spain: 30** litres/person·day.
- Operating days per week: **7 days**, as it is a dwelling.

Those are the needs and specifications of the house model. The heating energy needed in each house for DHW will be a result of the simulation, and therefore will appear in Chapter 5.3. Results of heating needs for DHW.

4.3.4 Analysis of the solar installation

Once, the heating needs to produce the DHW demand are know, the analysis over the characteristics of the solar installation will be performed.

Different analyses over the two houses are going to be done, changing one specification each time. The comparison, the study of the differences and improvement for the system, can be seen at Chapter 5. Results. These characteristics that are going to be changed are:

- Slope, β, of the collectors.
- Collector type: unglazed and evacuated tube collector.
- Collector area / number or collectors.

The common characteristics in the simulations for both countries are explained underneath these words.

Energy model

Resource assessment

- Solar tracking mode: **Fixed**.
- Slope: it is going to be the variable in the first analysis about the solar installation.
- Azimuth: **0º**, for both cases.

Solar water heater

- Collector type: this is the variable in the second analysis.
- Number of collectors: is the variable in the third analysis.
- Miscellaneous losses: **5%**.

  These losses are represented as a percentage of heating delivered. This value includes, for example, losses due to the obstruction of the solar collector by snow and/or dirt. The value of this parameter depends on local climatic conditions, on the tilt angle of the collector, and on the presence of personnel on-site to remove the snow or clean the collector. Depending on local conditions, this value ranges between 2 to 5% for evacuated tube collectors rack-mounted on flat surfaces or well-maintained collectors, and between 3 to 10% for other collectors. (Natural Resources Canada, 2010)

  As in this thesis evacuated tube collectors are going to be used, the worst situation will be chosen: 5% of losses. Also, this is valid for other kind of collectors, with a normal maintenance of snow and dirt, not especially well-maintained.

Balance of system & miscellaneous

- Storage: **Yes**

  Because systems without storage are typically industrial applications, and this is a dwelling.

- Storage capacity / solar collector area: **75 l/m².**

  The larger the storage, the better the system will be at going through long periods with little sunshine, although this will increase stand-by losses and initial equipment costs. As an initial estimate, a nominal value could be 75 l/m²; typical values range from 37.5 to 100 l/m². (Natural Resources Canada, 2010)

Another restriction is found at the Spanish regulations (CTE, 2009), which says that the Equation 4.3-1 must be fulfilled. Where V_s is the volume of the storage device [l] and A_{Tc} is the overall collector area [m^2]

$$50 < \frac{C_s}{A_{Tc}} < 180$$

Equation 4.3-1

Then to fulfil all the conditions, a value of 75 l/m² will be chosen. But, depending on the type of collector, if the resultant storage capacity is much lower/higher than the estimated DHW consumption for each country, this value would be increased/decreased.

- Heat Exchanger: **Yes**.

As the collector loop, primary system, is separated from the rest of the system, secondary system, by a heat exchanger. Then, an antifreeze fluid, such as glycol, circulates through the collector loop, thereby providing antifreeze protection to the system in the winter.

- Heat Exchanger efficiency: **80%.**

This value usually ranges from 50 to 85%, depending on the type of heat exchanger installed. As a typical starting point value for analysis, 80% is suggested. Note that the heat exchanger efficiency is not related to the heat losses of a heat exchanger, which are generally negligible. A higher efficiency characterises the ability of the heat exchanger to transfer the same amount of heat from the solar loop to the service hot water but with a narrower temperature difference. (Natural Resources Canada, 2010). Hence, the typical value of 80% is chosen.

- Miscellaneous losses: **7%**.

This value accounts for heat losses from the pipes and the tank to the surrounding environment. On one hand, piping losses depend on the length of piping; a value of 1 or 2% should be set if there is a short distance between the collector and the rest of the system, and between 4 and 8% otherwise. The lower values should be used for well-insulated piping and the higher values for poorly insulated piping. On the other hand, tank losses vary from 5 to 10%. These losses must be added to the piping losses. However, it must be noted that some of the heat losses from the tank and inside piping can provide space heating during winter months. (Natural Resources Canada, 2010)

For the simulations done in this thesis, is supposed that the distance between the collect ant the storage system is not so big, as so is the house. Then, for piping, a value of 2% losses will be considered, being in the conservative side and suppose the possibility that the piping is not well insulated. And about the tank losses, 5% of losses will be chosen, as is a small installation and the tank will be located inside the house. On the whole, there will be 7% of miscellaneous losses.

- Pump power / solar collector area: **5 W/m^2**

With indirect loop solar water heating systems, it is used an antifreeze mixture and if operating in cold climates, it is important to note that the pump power has to be greater than direct systems operated in mild climates. Table 4.3.7 shows the typical solar pumps for different collector aperture area.

Table 4.3.7. Typical solar pumps and their specific pump power range.

RETScreen

Collector aperture area (m^2)	Solar pump (W)	Specific pump power range (W/m^2)
2 to 6	20 to 45	3 to 20
6 to 12	85	7 to 15
12 to 35	185	5 to 15
35 to 60	205	3.5 to 6

www.retscreen.net

(Natural Resources Canada, 2010)

As the solar installation for these virtual houses is going to be small, for a single family house, the smallest type of pump will be chosen: 2 to 6 m^2 of collector surface area, so 3 to 20 W/m^2. And between this range, as nowadays the pups have very good performance, and the circuit is small, a low value will be chosen: 5 W/m^2.

- Electricity rate:

Table V.B.1, in Appendix V.B: Energy Statistics in EU, represents the domestic electricity prices for EU countries in 2011.

- **Finland: 0,1192 €/kWh**. As the consumption of this virtual house is going to be more than 7.500 kWh/year: 3,5 MWh for DHW and 20,5 MWh in heating, are 24 MWh per year.
- **Spain: 0,1696 €/kWh**. As the consumption of this virtual house is going to be more than 7.500 kWh/year: 1,7 MWh for DHW and 8 MWh in heating, are almost 10 MWh per year.

4.3.4.1 First analysis: Slope variation of the collectors

In the initial simulation, the slope is equal to the latitude, $\beta = \varphi$. Then, for each country separately, the slope is going to be modified till the maximum annual total irradiation is reached.

The software provides for each tilting angle, the daily solar radiation for each month in $kWh/m^2 \cdot day$, and then, the annual total radiation.

The process of this analysis will be performed by increasing and decreasing the tilting angle in a range of: $(\varphi - 10^o) < \beta < (\varphi + 10^o)$ with a 1º step. If the value of the annual solar radiation doesn't decrease, this would mean than the maximum has not been reached. In that case, another second iteration should be done, for a bigger range of values: $(\varphi - 20^o) < \beta$ and/or $\beta < (\varphi + 20^o)$, until the maximum is achieved. And if still it is not reached, the iteration will continue decreasing/increasing the value of β till the result is achieved.

For the other two analyses that are going to be done subsequently, the slope with which more amount of energy is received, $\beta_{opt,}$ will be used.

4.3.4.2 Second and third analysis: Collector type and area variation

The second analysis consists in varying the collector type. Two types of collectors will be studied: glazed and evacuated tube. The reason why unglazed collectors are not going to be considered is because they are not aimed for this installation. As explained in Chapter 2.4.3.1: Collectors, because this kind of collectors are not insulated, a large portion of the heat absorbed is lost, particularly when it is windy and not warm outside (i.e. Finnish climate), hence they are suited for low temperature applications where the demand temperature is below 30°C; and for DHW a temperature of 60 ºC is required.

About the third analysis, varying the collector area, it will be performed inside each second analysis for both two types of collectors. In other words: first, a glazed collector will be studied, and then its collector area will be modified; secondly, an evacuated tube collector will be simulated, and its collector area will be changed.

Though, there are many suppliers and different models of solar thermal collectors, and each one of them has its own surface area. This means that only the number of collectors can be modified in the software. Therefore, the collector area will be modified by increasing or decreasing the number of collectors.

The criteria for choosing a collector between all the manufacturers' database of RETScreen will be the same as explained in Chapter 2.4.3.1: Collectors, section *Applications of collectors.* For each collector, RETScreen database provides the value of the parameters: "$F_R\ (\tau\alpha)$" and "$F_R\ U_L$". The larger $F_R\ (\tau\alpha)$ is, the more efficient the collector is at capturing the energy from solar radiation. The smaller $F_R\ U_L$ is, the better the collector is at retaining the captured energy instead of losing it through convection and conduction to the ambient air.

For flat plate collectors, according to the purpose of the solar installation that is going to be studied, DHW in cold climates, the target group is "Groups III and IV". And its reference values are:

- Group III: Glazed collectors, insulated, one transparent cover and selective absorbent surface.
  - $0{,}75 < F_R\ (\tau\alpha) < 0{,}85$
  - $5 < F_R\ U_L < 6$ [W/ºC·m^2]
- Group IV: Glazed collectors, insulated and two transparent covers.
  - $0{,}7 < F_R\ (\tau\alpha) < 0{,}8$
  - $4 < F_R\ U_L < 6$ [W/ºC·m^2]

(Colectores de placa plana [Flat plate colectors], 2009)

Accordingly, the ranges that are valid for the two groups at the same time, for being in the more conservative situation, are:

- $0{,}75 < F_R\ (\tau\alpha) < 0{,}8$
- $5 < F_R\ U_L < 6$ [W/ºC·m^2]

For this reason, the collectors that will be used in the simulations and its characteristics are:

- Glazed collector:

The collector that fulfils all the specifications is represented in Table 4.3.8. It must me sais that it is a high quality collector.

Table 4.3.8. Chosen glazed collector and its characteristics.

Type	Glazed	
Manufacturer	Edwards Hot Water	
Model	SV Maxorb	
Gross area per solar collector	m²	1,97
Aperture area per solar collector	m²	1,81
Fr (tau alpha) coefficient		0,76
Fr UL coefficient	(W/m²)/°C	5,45

- Evacuated tube collector:

However, the ranges listed before are not valid for evacuated tubes. Then, the criteria for choosing a good evacuated tube collector will be as explained before: trying to look at the same time for the larger $F_R\ (\tau\alpha)$, which is how efficient the collector is at capturing the energy from solar radiation; and the smaller $F_R\ U_L$, which is how good is the collector is at retaining the captured energy instead of losing it through convection and conduction to the ambient air.

The collector that unifies both characteristics, from all RETScreen database is represented in Figure 4.3.9:

Table 4.3.9. Chosen evacuated tube collector and its characteristics.

Type	Evacuated	
Manufacturer	AMK-Solak Systems	
Model	OPC 15 S	
Gross area per solar collector	m²	2,13
Aperture area per solar collector	m²	1,71
Fr (tau alpha) coefficient		0,61
Fr UL coefficient	(W/m²)/°C	1,23

The analysis will be done by increasing the number of solar collectors, from one solar collector to four. Those values have been chosen because if more that 4 collectors are installed, the heating delivered does not increase significantly but the costs do. In other words, the energy received is not worthy compared with the costs of the installation with a big amount of collectors, for a house where an average of three persons live.

Related with the number of collectors, which means the area, the capacity of the system compared with the heating delivered will be studied and analyzed with the solar fraction obtained.

4.4 Economical analysis

Once the optimal number of collectors and the type of collector for each country is determined, the final heating delivered for DHW by the solar thermal installation is known. Then, this is the primary energy saved.

Therefore, an economic analysis will be done, to study the allowed investment of each installation. For that, Equation 4.4-1 will be used.

$$CRF \cdot I_{allowed} = Q_{saving} \cdot h_{energy}$$

Equation 4.4-1

Where each component means:

- CRF is the Capital Recovery Factor
- $I_{allowed}$ is the allowed investment [€]
- Q_{saving} is the energy saved by the renewable installation [kWh]
- h_{energy} is the price of the primary source of energy used in each case [€/kWh]

The CRF is expressed as:

$$CRF = \frac{i \cdot (1+i)^n}{(1+i)^n - 1}$$

Equation 4.4-2

Where:

- *i* is the interest rate [%]. A value of 0,04 will be chosen for both countries.
- *n* is the number of years. The investment will be considered to be covered in 20 years

Then, substituting these values on Equation 4.4-2, is obtained: CRF = 0,07.

5 Results

In this chapter, the results and analyses of the different simulations for the solar thermal installation in the virtual houses are explained.

5.1 Climate data verification

Before reaching any conclusion, is important to verify the veracity of the climate data that RETScreen software uses. However, has to be said that the data used in RETScreen is provided by NASA sources (NASA & Atmospheric Science Data Center, 2010).

5.1.1 Finnish climate data verification

In the Finnish building code (Rakennetun ympäristön osasto [Built Environment Division.], 2011), the information about total solar irradiation in the zone where Tampere is locate is given. In Table 5.1.1. can be seen that the total annual solar irradiation over a horizontal surface is 975 kWh/m^2.

Table 5.1.1. Total solar irradiation over a horizontal surface in Tampere area.

Tampere	Total solar irradiation [kWh/m²]
January	6,2
February	22,4
March	64,3
April	119,9
May	165,5
June	168,6
July	180,9
August	126,7
September	82,0
October	26,2
November	8,1
December	4,4
YEAR	975,2

(Rakennetun ympäristön osasto [Built Environment Division.], 2011)

On the other hand, the data provided by RETScreen is represented in Table 5.1.2. In there can be seen that the total solar irradiation is 979 kWh/m^2.

Table 5.1.2. Solar radiation over a horizontal surface in Tampere (RETScreen)

Tampere	Daily solar irradiation [kWh/m²/d]	Total solar irradiation [kWh/m²]
January	0,28	8,68
February	1,00	28,00
March	2,37	73,47
April	3,92	117,60
May	5,43	168,33
June	5,60	168,00
July	5,25	162,75
August	4,02	124,62
September	2,52	75,60
October	1,11	34,41
November	0,44	13,20
December	0,14	4,34
YEAR	2,68	979,00

Both values are very similar. Therefore, it can be said that the data provided by RETScreen about Tampere is objective and trustful.

5.1.2 Spanish climate data verification

For the case of the Spanish virtual house, located in Madrid, the official data has been provided by CENSOLAR (*Centro de Estudios de la Energía Solar [Solar Energy Training Centre]*); and is represented in Table 5.1.3. The original values in [MJ/m^2] of solar radiation for the main cities in Spain, where the values from Madrid were retrieved, can be seen at Table IV.C.1 (inside Appendix IV.C: Data in Spain)

Table 5.1.3. Total solar irradiation over a horizontal surface in Madrid [kWh/m^2].

Madrid	Daily solar irradiation [kWh/m^2/d]	Total solar irradiation [kWh/m²]
January	1,86	57,69
February	2,94	82,44
March	3,78	117,11
April	5,22	156,67
May	5,81	179,97
June	6,53	195,83
July	7,22	223,89
August	6,42	198,92
September	4,69	140,83
October	3,17	98,17
November	2,08	62,50
December	1,64	50,81
YEAR	4,28	1564,83

(CENSOLAR)

And the data that RETScreen has used for the simulations is shown in Table 5.1.4.

Table 5.1.4. Solar radiation over a horizontal surface in Tampere (RETScreen)

Madrid	Daily solar irradiation [kWh/m^2/d]	Total solar irradiation [kWh/m²]
January	2,01	62,31
February	2,93	82,04
March	4,38	135,78
April	5,41	162,30
May	6,39	198,09
June	7,41	222,30
July	7,51	232,81
August	6,59	204,29
September	5,05	151,50
October	3,27	101,37
November	2,20	66,00
December	1,64	50,84
YEAR	4,57	1669,63

Both values for total solar radiation, from CENSOLAR I_{Tcen} = 1.564,8 kWh/m^2, and from RETScreen I_{Tret} = 1.669,6 kWh/m^2, are not exactly the same, but sufficiently similar to be accepted as real data.

This difference exist due to some possible reasons: mainly because the measurements have not been taken from the same location, or because the year/s when those measurements were performed were not the same, the weather conditions were different, etc.; due to this reasons the values could differ but as can be seen, not that much.

5.1.3 Climate data conclusion

In both countries, the data for solar radiation provided by RETScreen has been considered real and valid for the analyses, even if for the case of Madrid the values differ slightly.

5.2 Non renewable analysis results

For the initial house, without any solar installation, the consumption of the heating system has been analyzed. The values of total heating needs that are going to be used in the solar thermal installation analyses are going to be:

- **Finland: 22 MWh/year**.
- **Spain: 10 MWh/year**.

If we had more information about the electricity consumption destined for space lighting, according to Finnish regulations, the maximum allowed primary energy consumption must have been analyzed. According to Table 3.3.2 (inside Chapter 3.3.4: Finnish regulations), the value of 204 kWh/m^2 per year for this kind of building, for a single primary source of energy, could not be surpassed.

5.2.1 Non renewable analysis conclusion

As expected, for the house in Finland is needed more power to heat the house, more than the double needed in Spain. This is, of course, because of the climate conditions, as all the characteristics of the house are the same for both cases.

5.3 Results of heating needs for DHW

The heating load depends on the occupants of the house, their occupancy rate, their daily DHW consumption, the temperature at which this water is heated, the operating days per week, and least but not last the water network temperature (provided by RETScreen data base).

The software simulates this situation for both countries and gives as a result the annual heating load:

- **Finland: 3,5 MWh/year**.
- **Spain: 1,7 MWh/year**.

5.3.1 Heating needs for DHW conclusion

It can be appreciated that the heating load in Finland is nearly the double as in the Spanish case. This is mainly because the reference values of DHW consumption given for both governments are quite different between each other. In Finland the average DHW consumption is 50 l/person·day meanwhile in Spain is only 30 l/person·day.

And secondly, even if in Spain the DHW consumption was the same as in Finland, the value obtained would be: 2,9 MWh/year, still lower than in Finland. This is because of the weather conditions. On one hand the water network temperature supplied in Finland is lower than in Spain, as can be seen in Table 5.3.1 (data provided by RETScreen), therefore more energy to heat the water, till the 60 ºC required, is needed.

Table 5.3.1. Water network temperature in Tampere and Madrid.

Water temperature (ºC)	Tampere	Madrid
Minimum	1,0	11,5
Maximum	8,8	17,9

And on the other hand, the outer temperature is less, the surface of the collectors are colder, and of course, the solar radiation received in Finland is lower than in Spain, because of the climate, geographical situation and weather conditions (i.e. snow, wind, etc.)

5.4 Solar installation analysis results

5.4.1 First analysis results: Slope variation of the collectors

Each house has been analyzed separately. The slope has been modified increasing and decreasing the tilting angle in a range of: (φ – 10º) < β < (φ + 10º) with a 1º step. The results are shown below.

5.4.1.1 Slope variation in Tampere

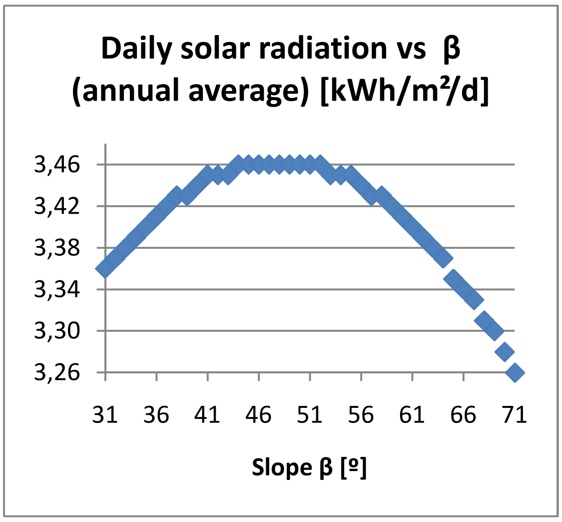
With the initial slope: $\beta = \varphi_{\text{Tampere}} = \mathbf{61°}$, RETScreen provides the average daily solar radiation data per month, which is shown in Table 5.4.1.

Table 5.4.1. Daily solar radiation in Tampere, horizontal and for β = 61º.

Month	Daily solar radiation - horizontal	Daily solar radiation - tilted
	kWh/m²/d	kWh/m²/d
January	0,28	1,32
February	1,00	2,88
March	2,37	4,34
April	3,92	4,71
May	5,43	5,22
June	5,60	4,88
July	5,25	4,75
August	4,02	4,27
September	2,52	3,54
October	1,11	2,35
November	0,44	1,73
December	0,14	0,79
Annual	**2,68**	**3,40**

Annual solar radiation - horizontal:	**0,98 MWh/m²**
Annual solar radiation - tilted:	**1,24 MWh/m²**

As can be seen, the annual solar radiation in Tampere, for β = 61º is 1,24 MWh/m^2. This is the value that must be maximized. Then, after performing the iterations, the results are represented in Figure 5.4.1. The values of the iterations are listed in Table VI.3, inside Appendix VI: Tables and figures from analyses.



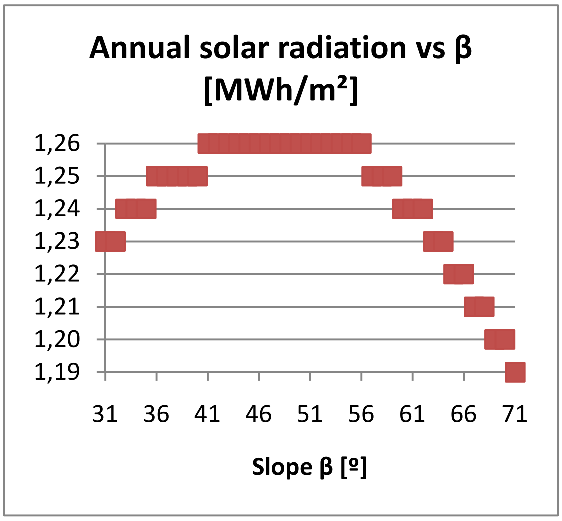


Figure 5.4.1. Solar radiation results from the slope variation in Tampere.

From this results can be deduced that the maximum amount of annual solar radiation that is possible to receive in Tampere is 1,26 MWh/m^2 for a tilting range of β = [41º, 56º], meanwhile the average of daily solar radiation is 3,46 kWh/m^2/day β = [44º, 52º].

Hence, for being sure that the situation is the optimized, the middle value of slope angle will be chosen, that is: β = 48º; a value 13º lower than the supposed to be optimum that is the latitude.

Table 5.4.2 shows the solar radiation data, annual and per month, that RETScreen provides for this tilting angle.

Table 5.4.2. Daily solar radiation in Tampere, horizontal and for β_{optT} = 48º.

Month	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d
January	0,28	1,18
February	1,00	2,65
March	2,37	4,18
April	3,92	4,87
May	5,43	5,60
June	5,60	5,33
July	5,25	5,15
August	4,02	4,51
September	2,52	3,57
October	1,11	2,24
November	0,44	1,56
December	0,14	0,69
Annual	**2,68**	**3,46**

Annual solar radiation - tilted:	**1,26 MWh/m²**
Annual solar radiation - horizontal:	**0,98 MWh/m²**

Then, it has been proved that the maximum solar radiation that is possible to attain is I_T = 1,26 MWh/m^2, for a tilting angle of β = 48º = β_{optT}. Which means that tilting the surface less to the south, more solar energy is received mainly in the months around summer. The only bad issue about tilting the surface like this is that, this way, the amount of energy intercepted in winter is much lower than in the initial situation, therefore this installation with this tilting is optimized for summer season.

This solar radiation data shown above is the one that is going to be used by RETScreen for the rest of the analyses, for the virtual house in Tampere.

5.4.1.2 Slope variation in Madrid

The initial value for the slope in the house located in Madrid is: $\beta = \varphi_{\text{Madrid}}$ = **40°.** RETScreen provides the average daily solar radiation data per month in this city, with this tilting value, which is shown in Table 5.4.3.

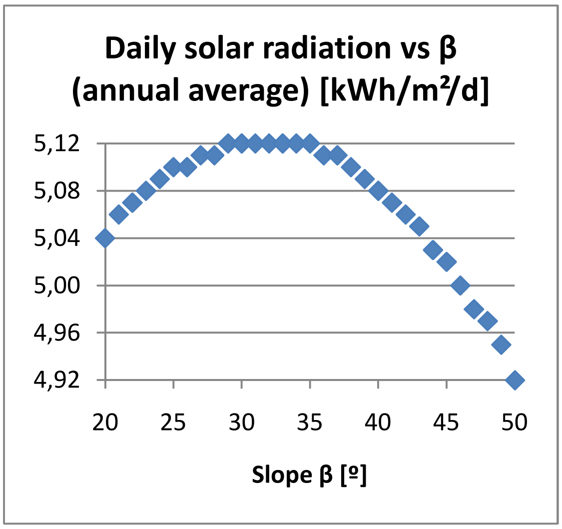
As there can be seen, the annual solar radiation for β = 40º is 1,85 MWh/m^2. This is the value that is trying to be maximized. Then, after performing the needed iterations, the results are illustrated in Figure 5.4.2. The numeric values of the iterations are listed in Table VI.4.

Table 5.4.3. Daily solar radiation in Madrid, horizontal and for β = 40º .

Month	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d
January	2,01	3,41
February	2,93	4,25
March	4,38	5,38
April	5,41	5,62
May	6,39	5,91
June	7,41	6,49
July	7,51	6,73
August	6,59	6,55
September	5,05	5,84
October	3,27	4,38
November	2,20	3,56
December	1,64	2,83
Annual	**4,57**	**5,08**

Annual solar radiation - tilted:	**1,85 MWh/m²**
Annual solar radiation - horizontal:	**1,67 MWh/m²**

Paying attention to the Figure 5.4.2, there can be seen that the maximum amount of energy received has been achieved: the maximum average daily solar radiation is 5,12 kWh/m^2/day for a tilting range of β = [29º, 35º], and the maximum amount of annual solar radiation that is possible to receive in Madrid is 1,87 MWh/m^2 for a tilting range of β = [27º, 36º].



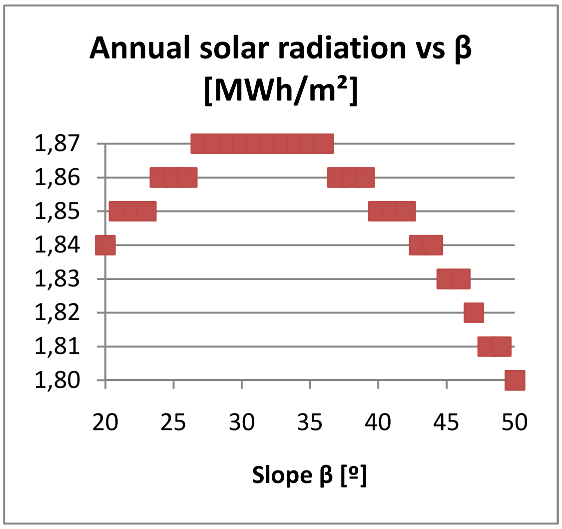


Figure 5.4.2. Solar radiation results from the slope variation in Madrid.

Thus, for being sure that the situation is the optimized, the middle value of tilting angle will be chosen. The interval from which this value is going to be subtracted is the one of maximum daily solar radiation, as it is smaller than the interval for annual solar radiation, but still is inside this last one.

That is: β_{optM} = 32º; a value 8º lower than the supposed to be optimum, which is the latitude (40º).

Table 5.4.4 shows the solar radiation data, annual and per month, that RETScreen provides for this optimum tilting angle.

Table 5.4.4. Daily solar radiation in Madrid, horizontal and for β_{optM} = 32º.

Month	Daily solar radiation - horizontal	Daily solar radiation - tilted
	kWh/m²/d	kWh/m²/d
January	2,01	3,23
February	2,93	4,10
March	4,38	5,33
April	5,41	5,74
May	6,39	6,17
June	7,41	6,85
July	7,51	7,07
August	6,59	6,75
September	5,05	5,85
October	3,27	4,28
November	2,20	3,39
December	1,64	2,66
Annual	**4,57**	**5,12**
Annual solar radiation - tilted:		**1,87 MWh/m²**
Annual solar radiation - horizontal:		**1,67 MWh/m²**

In conclusion, for obtaining more solar energy in Madrid, the collector surface must be tilted 32º from the horizontal, heading south. The fact that the tilting angle is lower than the latitude means that this disposition is for giving preferential use in summer for the installation.

5.4.1.3 Slope variation conclusions

In both cases the optimal tilting angle has been lower than in the initial case, where the slope is equal to the latitude.

- **Finland:** β_{optT} = 48º = φ – 13º.
- **Spain:** β_{optM} = 32º = φ – 8º.

This indicates that, as explained in the previous chapter, this way the installation is being designed for having preferential summer consumption.

For the Finnish case this situation is more noticeable, as the tilting has been more than the β = φ - 10º. But it is understandable, as in Finland, the sun in summer is very high. Also, making this installation as winter preferential consumption in Finland does not make sense, as the energy received in December, January and February is almost neglectable; adding the fact that the snow should be removed regularly so the collectors are not covered.

In conclusion, for the Finnish situation it is a good choice leaving the tilting angle in its optimal slope. And for Spain, even if the optimal angle is for preferential summer, it is usually tilted for annual preference consumption, so that more energy in colder months will be received when more needed, decreasing slightly the total annual solar radiation received for a better good.

5.4.2 Second and third analysis results

For every simulation there are some conditions that must be fulfilled. These conditions are listed in Chapters 3.3.3. Finnish regulations and 3.4.3. Spanish regulations, and the ones concerning with these analyses are:

Total collector area

For a DHW installation, the total collector area must be so that Equation 5.4-1 is fulfilled.

$$50 < \frac{V_s}{A_{Tc}} < 180$$

Equation 5.4-1

Initially, the value 75 l/m² will be the starting point, and the value of V_s is approximately the daily DHW demand in the house. Then, as the collector area will increase when the number of collectors is increased, this value must me modified, taking into account the limits.

This design criteria is imposed by the Spanish Technical Building Code (CTE, 2009); but in this analyses will be used for both countries.

Solar fraction

For service hot water systems with storage, this value can range from 10 to 70%. Solar water heating systems designed for year-long operation in temperate climates will have solar fractions typically between 30 and 50%. (Natural Resources Canada, 2010)

There is a minimum solar fraction the Spanish case. It cannot be applicable for Finland as it is based in climatic conditions for Spain, much warmer than Finland and receive more solar radiation. For the city of Madrid, as it is the climatic area IV and the total demand of the building is less than 5.000 l/day, the minimum solar fraction must be 60%.

5.4.2.1 Glazed collector

As explained in the analysis chapter, the glazed collector that is used if from *Edwards Hot Water* manufacturer, and the model is called *SV Maxorb*. Its characteristics are listed in Table 4.3.8 (inside Chapter 4.3.4.2: Second and third analysis: Collector type and area variation).

Four iterations have been done, analyzing the characteristics: total solar collector area, capacity of the collectors, storage capacity, electricity consumed by the pump, DHW heating delivered, and solar fraction. From these values obtained from the program, the DHW not covered can be also seen as a result. The results for each analysis are explained below.

Glazed collector area variation in Tampere

Table 5.4.5. represents the variation of the characteristics studied related with the area of the collectors

Table 5.4.5. Results of the iterations for glazed collectors in Tampere.

Tampere - Glazed	Units	Number of collectors			
		1	2	3	4
Solar collector area	m^2	1,97	3,94	5,91	7,88
Capacity	kW	1,27	2,53	3,80	5,07
Storage cap./col.area	l/m^2	80	50	50	50
DHW demand	l	150	150	150	150
Storage capacity	l	144,7	180,9	271,4	361,8
Electricity - pump	MWh	0,0	0,0	0,0	0,0
Solar fraction	%	26	43	54	61
DHW heating delivered	MWh	0,9	1,5	1,9	2,2
DHW heating demand	MWh	3,5	3,5	3,5	3,5
DHW not covered	MWh	2,6	2,0	1,6	1,3

Total collector area

The coefficient storage capacity / collector area must never be lower than 50 l/m^2, and the storage capacity must be a value similar to the daily DHW demand. When there are three or more collectors installed, the total collector area increases at a point that the value 50 l/m^2 cannot be surpassed; as a result, the storage capacity increases exceeding and even doubling the DHW demand value, as can be seen in Figure 5.4.3.

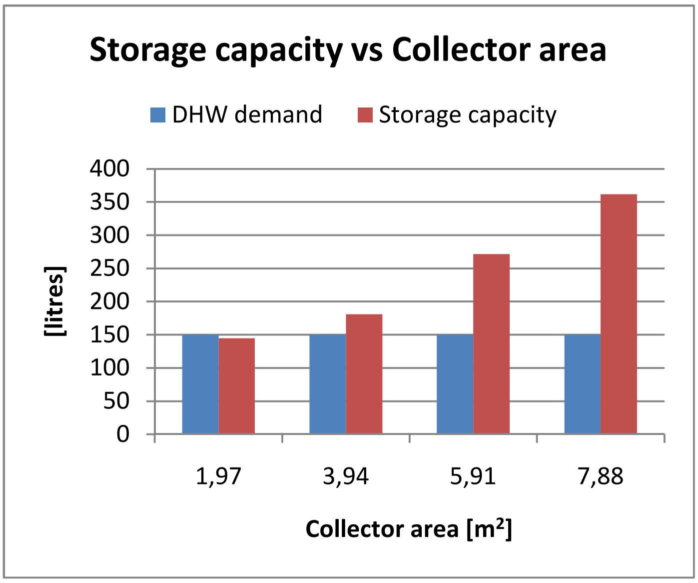


Figure 5.4.3. Storage capacity Vs collector area, for glazed collectors in Tampere.

Thus, the number of collectors according to this restriction is less than three, which means one or two glazed collectors.

Electricity - pump

As the order of magnitude for quantifying energy consumption is MWh, the power used by the pump is neglectable. This is why in Table 5.4.5. appears as zero.

Solar fraction

The percentage of DHW provided by solar energy increases when the total collector area increases as well.

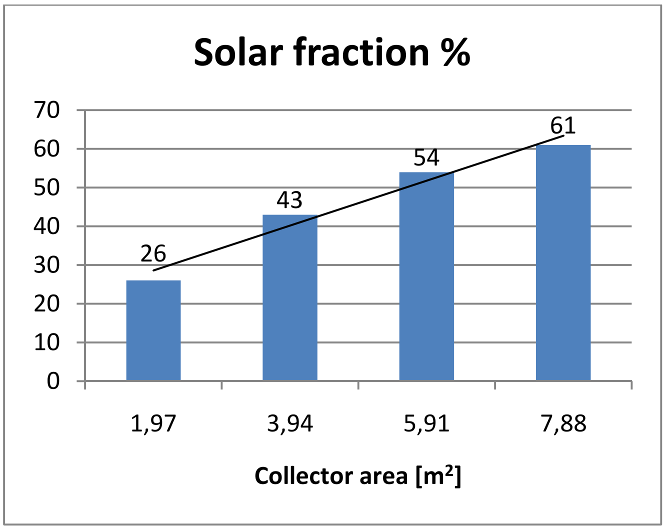


Figure 5.4.4. Solar fraction for different glazed collector areas in Tampere.

However, as can be seen in Figure 5.4.4, it is not completely a linear increase; which leads to think that even if the number of collectors is increased, is very unlikely to obtain a 100% of solar fraction. This data does help to decide the optimum number of collectors.

DHW heating

The DHW demand is 3,5 MWh. Figure 5.4.5 illustrates the part of this DHW demand delivered by the solar installation, color blue in the graph, meanwhile the demand that is not covered is represented in color red.

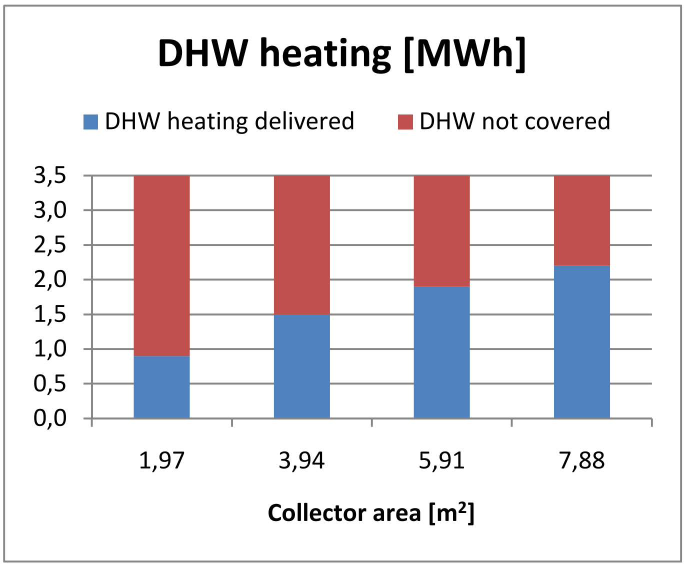


Figure 5.4.5. DHW heating delivered and not covered for glazed collectors in Tampere.

If the total collector area increases, the DHW heating delivered by solar energy also increases. However, it must be taken into account if it is worthy to install more solar collectors for a low energy saving. For example, if there are already two collectors, when installing the third one, less that 1MWh of electricity is saved.

RETScreen recommendation

Once the type of collector is chosen, the software proposes the number of collectors for the simulation. For this case, RETScreen has proposed to use two glazed collectors.

Glazed collector area variation in Madrid

In Table 5.5.6 are listed the results of the iterations. As can be seen in the values, the 4th iteration does not make sense, as all the energy is covered by the installation, which is highly unlikely due to overheating in summer months.

Table 5.4.6. Results of the iterations for glazed collectors in Madrid.

Madrid - Glazed	Units	Number of collectors			
		1	2	3	4
Solar collector area	m^2	1,97	3,94	5,91	7,88
Capacity	kW	1,27	2,53	3,80	5,07
Storage cap./col.area	l/m^2	50	50	50	50
DHW demand	l	90	90	90	90
Storage capacity	l	90,5	180,9	271,4	361,8
Electricity - pump	MWh	0,0	0,0	0,0	0,0
Solar fraction	%	63	82	91	98
DHW heating delivered	MWh	1,1	1,4	1,6	1,7
DHW heating demand	MWh	1,7	1,7	1,7	1,7

Total collector area

The coefficient storage capacity / collector area must never be lower than 50 l/m^2, and the storage capacity must be a value similar to the daily DHW demand, which in this case is 90 l.

When there are two or more collectors installed, the total collector area increases at a point that the value 50 l/m^2 cannot be surpassed. As a result, the storage capacity increases exceeding exaggeratedly the DHW demand value from the third collector installed, as can be seen in Figure 5.4.6.

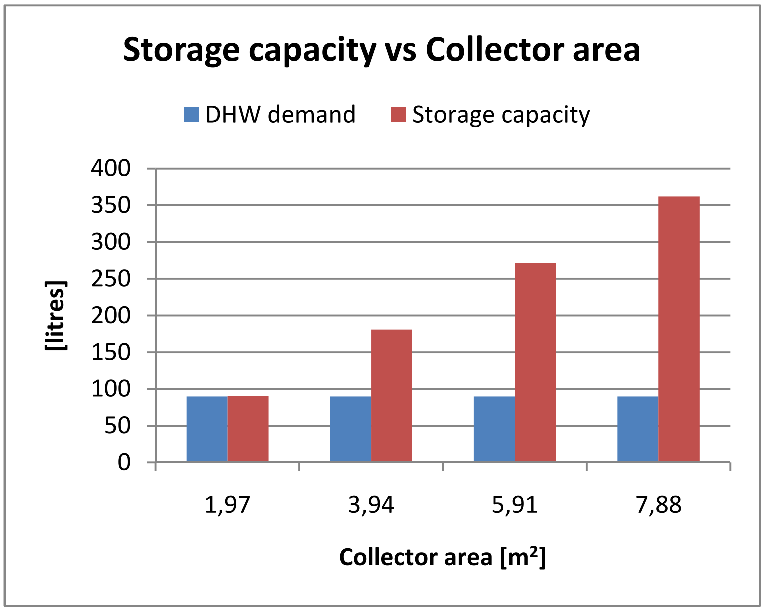


Figure 5.4.6. Storage capacity Vs collector area, for glazed collectors in Madrid.

Thus, the number of collectors according to this restriction is one or maybe two, but not recommended.

Electricity - pump

As well as for the case of Tampere, the power used by the pump is also neglectable. In Table 5.4.6 appears as zero.

Solar fraction

According to Spanish regulations (CTE, 2009), the monthly solar fraction must not be 100% during 3 consecutive months, and each moth must never surpass 110%. Also, this annual value must be between 10 and 70% in DHW installations.

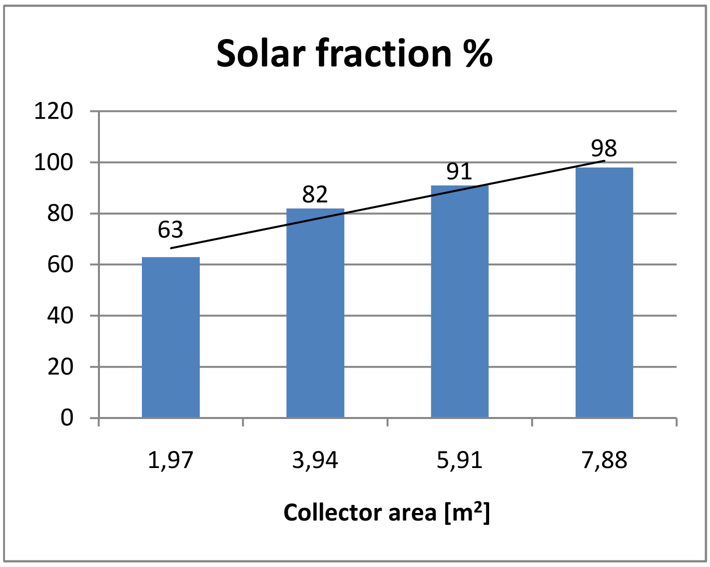


Figure 5.4.7 Solar fraction for different glazed collector areas in Madrid.

As shown in Figure 5.4.7, the percentage of DHW provided by solar energy increases with the area till reaching the maximum. This situation, with over 90% of annual solar fraction, can only happen because in the sunnier months the monthly restrictions of the 100% during three consecutive months and the limit of 110% are surpassed.

Also, the restriction imposed by the Spanish Building Code is fulfilled for all the cases. This restriction imposes that the solar fraction must be at least 60%.

Hence, due to overheating risks, the number of collectors should be one or maybe two, making sure that no monthly overheating occurs.

DHW heating

The DHW demand for the Spanish case is 1,7 MWh. Figure 5.4.8 shows the part of this DHW demand delivered by the solar installation, color blue in the graph, and the demand that is not covered is represented in color red.

In an ideal case, this figure shows that with three or four collectors all the DHW demand is covered. However, as explained before, due to overheating, is not possible to have this big amount of energy received in summer months; also because the fact that producing more that 100% of the needs in summer does not help for winter months.

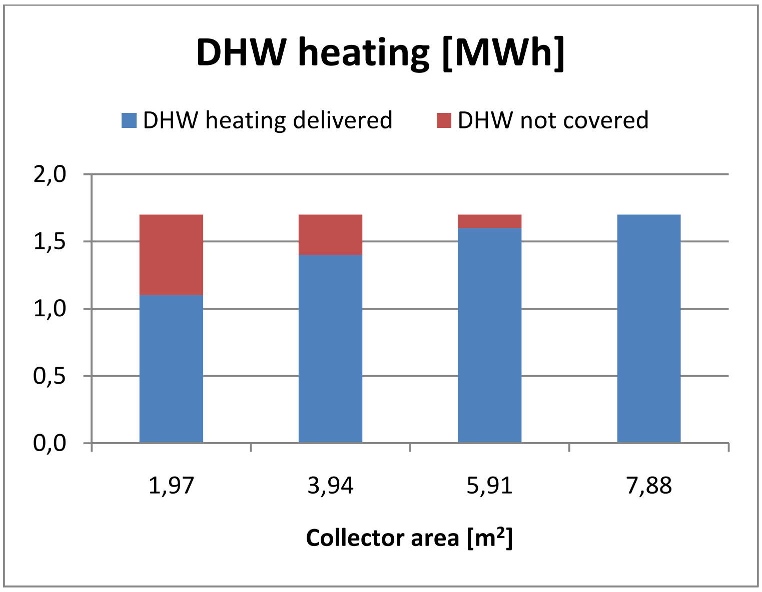


Figure 5.4.8. DHW heating delivered and not covered for glazed collectors in Madrid.

In conclusion, as in the other characteristics can be analyzed, the optimal number of collectors is one or two.

RETScreen recommendation

For this case, the software proposes that the number of glazed collectors must be one.

5.4.2.2 Evacuated tube collector

As explained in the analysis chapter, the glazed collector that is used if from *AMK–Solak Systems* manufacturer, and the model is called *OPC 15 S.* Is the only one that unifies both qualities at the same time, and its characteristics are listed in Table 4.3.9 (inside Chapter 4.3.4.2: Second and third analysis: Collector type and area variation).

The same iterations as the glazed collector analysis have been done.

Evacuated tube collector area variation in Tampere

Table 5.4.7 represents the variation of the characteristics studied related with the total area of the collectors.

Table 5.4.7 Results of the iterations for evacuated collectors in Tampere.

Tampere - Glazed	Units	Number of collectors			
		1	2	3	4
Solar collector area	m^2	2,13	4,26	6,39	8,52
Capacity	kW	1,20	2,40	3,60	4,79
Storage cap./col.area	l/m^2	88	50	50	50
DHW demand	l	150	150	150	150
Storage capacity	l	150,7	171,2	256,8	342,4
Electricity - pump	MWh	0,0	0,0	0,1	0,1
Solar fraction	%	32	55	70	76
DHW heating delivered	MWh	1,1	2,0	2,5	2,7
DHW heating demand	MWh	3,5	3,5	3,5	3,5
DHW not covered	MWh	2,4	1,5	1,0	0,8

Total collector area

The coefficient storage capacity / collector area must never be lower than 50 l/m^2, and the storage capacity must be a value similar to the daily DHW demand.

When there are three or more collectors installed, the total collector area increases at a point that the value 50 l/m^2 cannot be surpassed. As a result, the storage capacity increases exceeding and even doubling the DHW demand value, as can be seen in Figure 5.4.9.

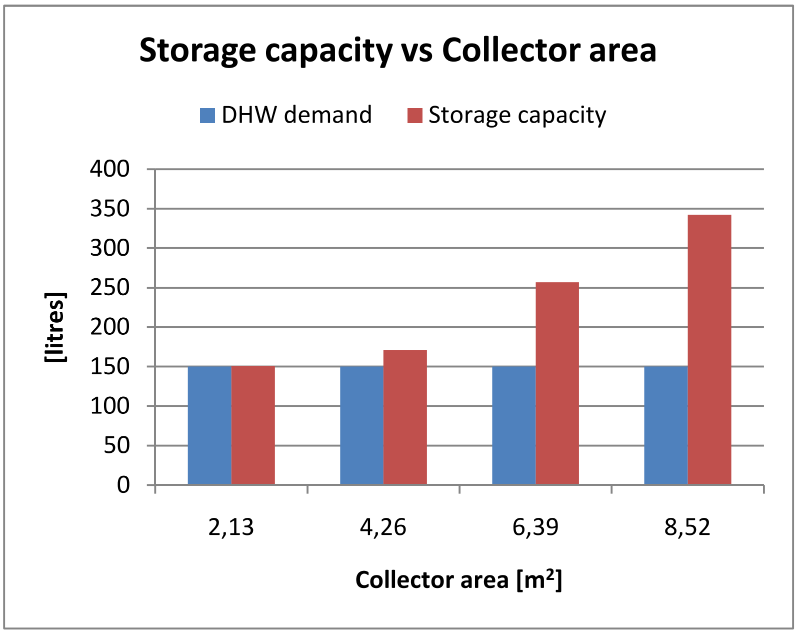


Figure 5.4.9. Storage capacity Vs collector area, for evacuated collectors in Tampere.

Thus, the number of collectors according to this restriction is less than three, which means one or two evacuated collectors. The same happened with glazed collectors.

Electricity - pump

On the contrary as for glazed collectors, for evacuated tubes when there are three or more collectors installed, the electricity spent in pumping is no longer neglectable. As can be seen in Table 5.4.7, the energy consumption of the pump for larger collector areas is 0,1 MWh.

Solar fraction

The percentage of DHW provided by solar energy increases when the total collector area increases as well.

However, as can be seen in Figure 5.4.10, it is not completely a linear increase. From three collectors installed, the solar fraction only improves 6%, compared with the 23% that increases from one collector to two.

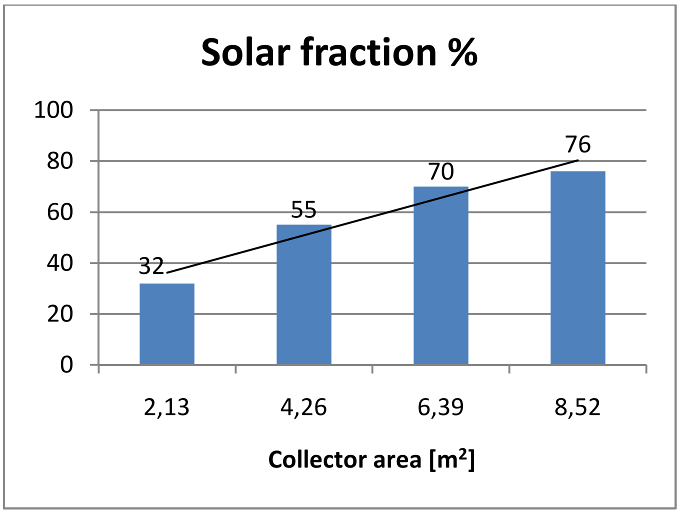


Figure 5.4.10. Solar fraction for different evacuated collector areas in Tampere.

In summary, based on this graph, the ideal number of collectors will be two or three. However, the price of installing a third collector, for having a 15% more of solar energy, must be considered.

DHW heating

The overall DHW demand is 3,5 MWh. Figure 5.4.11 illustrates the part of this DHW demand delivered by the solar installation, color blue in the graph, meanwhile the demand that is not covered is represented in color red.

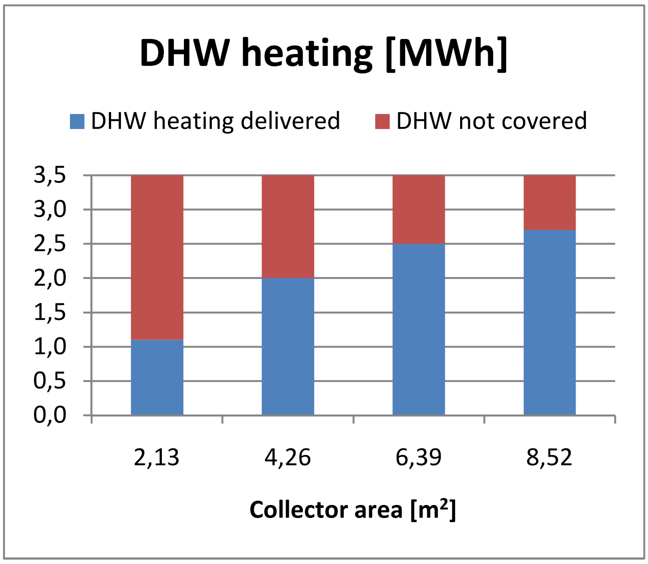


Figure 5.4.11. DHW delivered and not covered for evacuated collectors in Tampere.

If the total collector area increases, the DHW heating delivered by solar energy also increases. However, it must be taken into account if it is worthy to install more solar collectors for a low energy saving. For example, if there are already two collectors, when installing the third one, just 0,5 MWh of electricity is saved. And installing a fourth collector would not make sense, as the energy benefit is insignificant.

In conclusion, the optimum number of collectors in the solar installation is two.

RETScreen recommendation

For this case, RETScreen proposes to use two evacuated tube collectors.

Evacuated tube collector area variation in Madrid

In Table 5.4.8 are listed the results of the iterations. As can be seen, the 4th iteration has been removed because the maximum of all the need has been reached in the third iteration. And if the situation in the third iteration is unlikely due to overheating, the fourth iteration just does not make sense.

Table 5.4.8 Results of the iterations for evacuated collectors in Madrid.

Madrid - Glazed	**Units**	**Number of collectors**		
		1	**2**	**3**
Solar collector area	m^2	2,13	4,26	6,39
Capacity	kW	1,20	2,40	3,60
Storage cap./col.area	l/m^2	53	50	50
DHW demand	l	90	90	90
Storage capacity	l	90,7	171,2	256,8
Electricity - pump	MWh	0,0	0,0	0,0
Solar fraction	%	78	95	99
DHW heating delivered	MWh	1,4	1,7	1,7
DHW heating demand	MWh	1,7	1,7	1,7
DHW not covered	MWh	0,3	0,0	0,0

Total collector area

The coefficient storage capacity / collector area must never be lower than 50 l/m^2, and the storage capacity must be a value similar to the daily DHW demand, which in this case is 90 l.

When there are two or more collectors installed, the total collector area increases at a point that the value 50 l/m^2 cannot be surpassed. As a result, the storage capacity increases exceeding exaggeratedly the DHW demand value for the third collector installed, as can be seen in Figure 5.4.12.

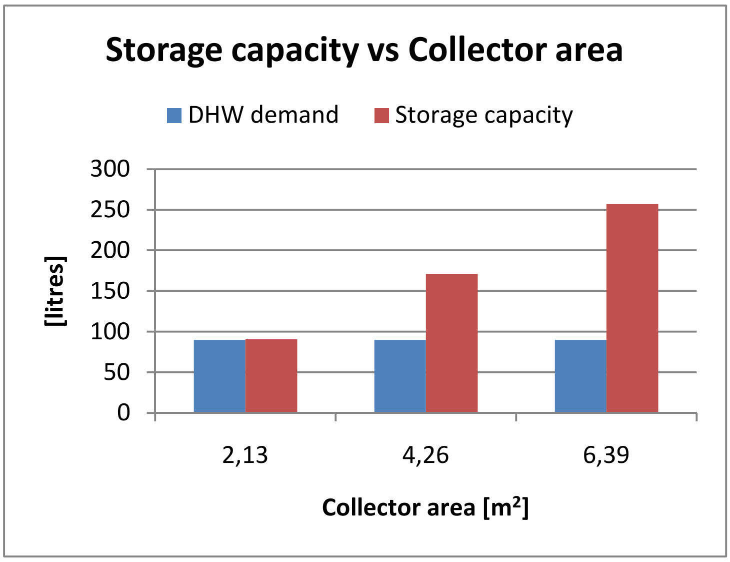


Figure 5.4.12. Storage capacity Vs collector area, for evacuated collectors in Madrid.

Thus, the number of collectors according to this restriction is one or maybe two, just in case there is an over demand, but it is not recommended. If the same DHW consumption were supposed for both countries, 50 l/person·day, the storage capacity should be 150 l, so the Spanish installation would need two collectors installed.

Electricity - pump

As well as for the case of glazed collectors, the power used by the pump is also neglectable. In Table 5.4.8 appears as zero.

Solar fraction

According to Spanish regulations (CTE, 2009), the monthly solar fraction must not be 100% during 3 consecutive months, and each moth must never surpass 110%. Also, this annual value must be between 10 and 70% in DHW installations.

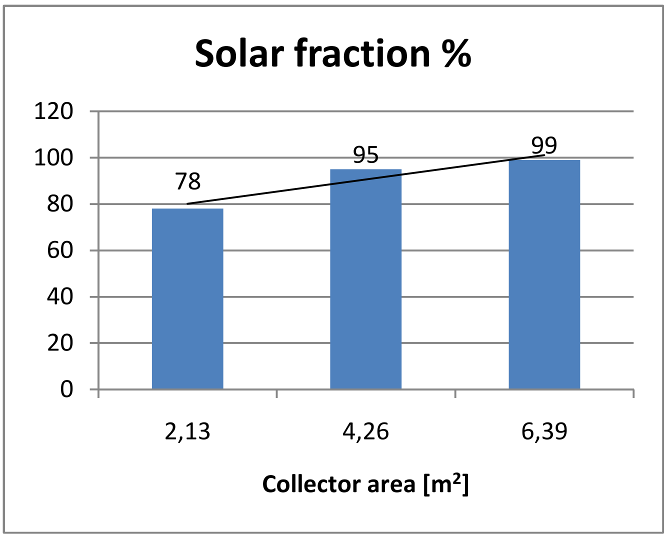


Figure 5.4.13 Solar fraction for different evacuated collector areas in Madrid.

As shown in Figure 5.4.13, the percentage of DHW provided by solar energy increases with the area till reaching the maximum.

This situation, with over 90% of annual solar fraction, can only happen because in the sunnier months the monthly restrictions of the 100% during three consecutive months and the limit of 110% are surpassed.

Also, the restriction imposed by the Spanish Building Code is fulfilled for all the cases. This restriction imposes that the solar fraction must be at least 60%.

Hence, due to overheating risks, the number of collectors for this solar installation should be one.

DHW heating

The DHW demand for the Spanish case is 1,7 MWh. Figure 5.4.14 shows the part of this DHW demand delivered by the solar installation, color blue in the graph, and the demand that is not covered is represented in color red.

In an ideal case, this figure shows that with two collectors all the DHW demand is already covered. However, as explained before, due to overheating, is not possible to have this big amount of energy received in summer months; also because the fact that producing more that 100% of the needs in summer does not help for winter months.

In conclusion, the optimal number of evacuated tube collectors installed is one.

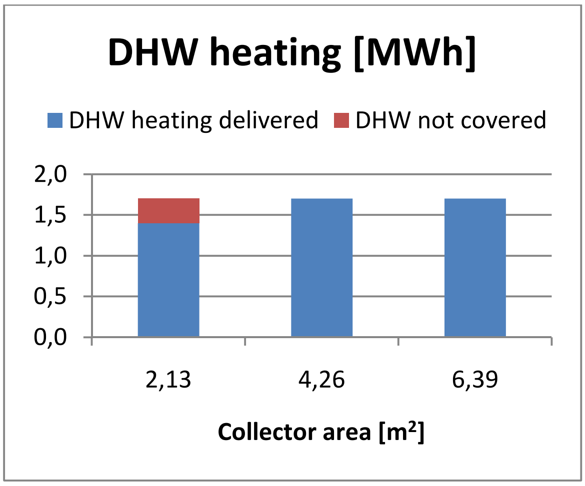


Figure 5.4.14. DHW delivered and not covered for evacuated collectors in Madrid.

RETScreen recommendation

For this case, the software proposes that the number of evacuated tube collectors must be one.

5.4.2.3 Collector type and area variation conclusions

First of all, it must be said that both collector models, the chosen for glazed and for evacuated type, are high quality collectors. So this must be taken into account because that means: they are more expensive than the other average collectors available in the market, and their performance is better.

Conclusions for the Finnish situation

For both types of collectors, the optimum **number of collectors is two**. However, it must be considered that the collector area of each collector type is different, though slightly similar.

And about which type of collector must be used, Table 5.4.9. represents the comparison between both types, for making the comparison easier.

Table 5.4.9. Comparison between glazed and evacuated collectors in Tampere.

Tampere	Units	Glazed	Evacuated
Solar collector area	m^2	3,94	4,26
Capacity	kW	2,53	2,40
Storage cap./col.area	l/m^2	50	50
DHW demand	l	150	150
Storage capacity	l	180,9	171,2
Electricity - pump	MWh	0,0	0,0
Solar fraction	%	43	55
DHW heating delivered	MWh	1,5	2,0
DHW heating demand	MWh	3,5	3,5
DHW not covered	MWh	2,0	1,5

The solar collector area for the two evacuated tube collectors is 8% bigger than the glazed collectors', so this could be a small reason why the performance of evacuated collectors is better.

Even though, a comparison about the solar fraction and the DHW demand covered, which represented in Figure 5.4.15, will be done.

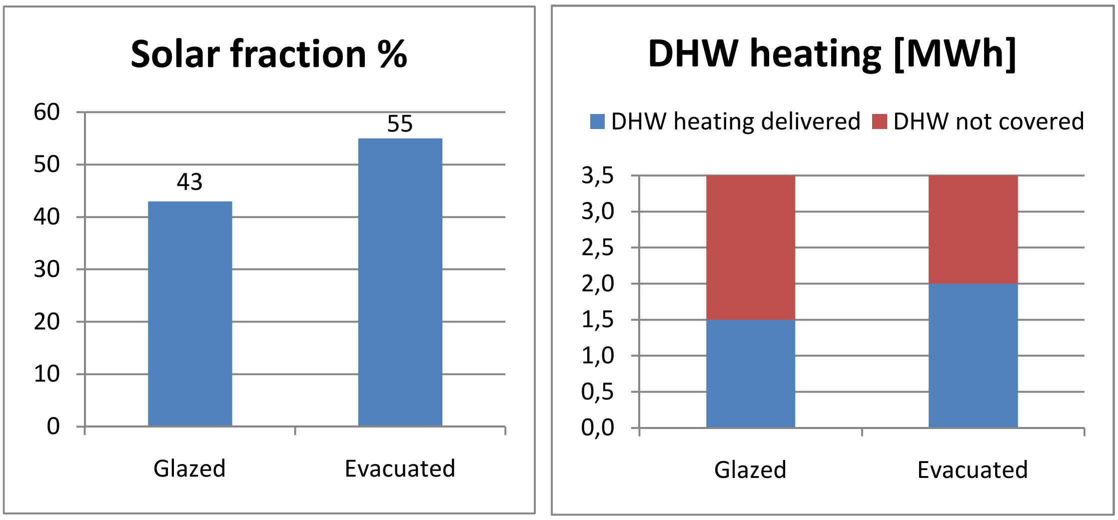


Figure 5.4.15. Solar fraction and DHW comparison for different collector types.

Evacuated tube collectors contribute 0,5 MWh more of DHW heating demand than glazed. And the solar resource is better used in evacuated collectors, as can be seen in the solar fraction chart. So, even if the total collector area of glazed is lower than evacuated, the performing of these last ones is much better.

However, before deciding which collector to acquire, the economical aspects must be taken into account, as evacuated tube collectors are more expensive than glazed, though the energetic benefits are not so different. Hence, **two glazed collectors** is the best option for the Finnish case. But if the **budget is not a constraint** for the project, the best choice would be **two evacuated tube collectors**.

Conclusions for the Spanish situation

After the results obtained, there are three possibilities for the Spanish virtual house, which are summarized in Table 5.4.10.

Table 5.4.10. Comparison of the possibilities for the Spanish case.

Madrid	Units	Glazed		Evacuated
		1	2	
Solar collector area	m^2	1,97	3,94	2,13
Capacity	kW	1,27	2,53	1,20
Storage cap./col.area	l/m^2	50	50	53
DHW demand	l	90	90	90
Storage capacity	l	90,5	180,9	90,7
Electricity - pump	MWh	0,0	0,0	0,0
Solar fraction	%	63	82	78
DHW heating delivered	MWh	1,1	1,4	1,4
DHW heating demand	MWh	1,7	1,7	1,7
DHW not covered	MWh	0,6	0,3	0,3

As explained in the previous subchapters, the possibilities are: one or two glazed, and one evacuated collector. Then, a comparison about its performance will be done.

For that, Figure 5.4.16 represents the solar fraction comparison, as well as the DHW demand covered for each case.

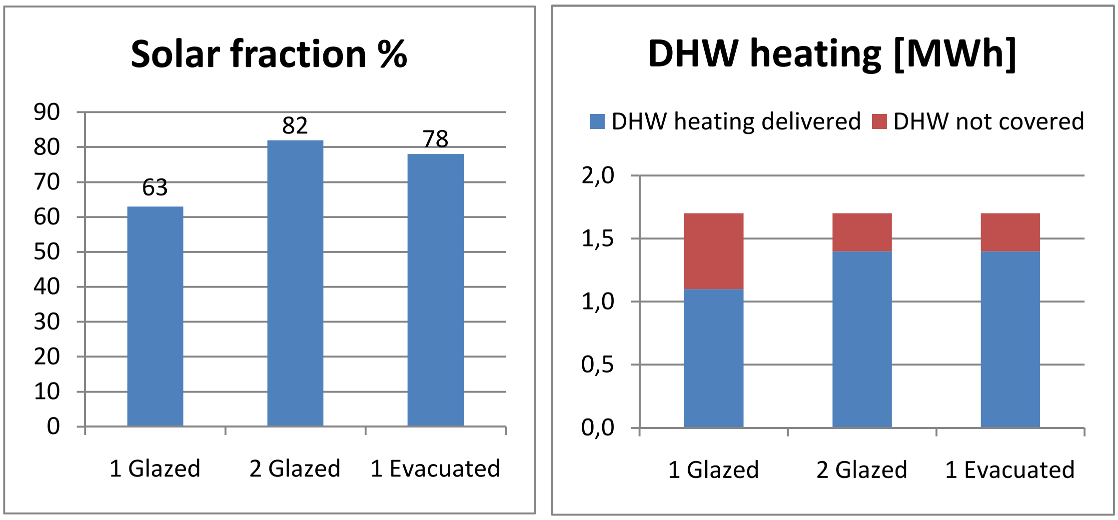


Figure 5.4.16. Solar fraction and DHW heating for the possibilities in Madrid.

The solar fraction obtained by the two glazed collectors and the single evacuated tube collector is very similar. The same happens with the DHW covered by the solar installation of these two possibilities. However, for the two glazed collectors, as the total solar collector area is bigger, a bigger storage device must be needed (reference value: 180,9 l).

Then, for the same performance, if two glazed collectors must be acquired instead of one evacuated, and is needed a bigger storage volume, glazed collectors are the less recommendable, as it is the most expensive solution.

To conclude, the best choice for the Spanish situation is **one evacuated tube collector**.

Another conclusion that can be derived from this analysis is that the tilting of the collectors is Spain should be performed for annual preferential consumption (β = φ) or even winter preferential (β = φ + 10º). Because this way overheating situations in the sunnier months are avoided and more advantage from the solar resource is taken for the months where the demand is higher, that is in winter.

5.5 Economical analysis

In this subchapter, the allowed investment for the solar thermal installation for DHW in each country will be obtained. As explained in the previous chapter, Equation 4.4-1 will be used, with a *CRF* of 0,07.

5.5.1 Economical analysis for Finland

For Finland, the solar thermal solution has been: two glazed collectors. And with this installation 1,5 MWh, of the 3,5 MWh DHW heating demand, is covered.

Then, the allowed investment for the solar installation in Finland is expressed by the Equation 5.5-1.

$$CRF \cdot I_{allowedF} = Q_{savingF} \cdot h_{energyF}$$

Equation 5.5-1

Where each component is:

- $I_{allowedF}$ is the allowed investment for the Finnish case. It is the value that will be subtracted.
- $Q_{savingF}$ is the energy saved by the renewable installation in Finland [kWh]. For two glazed collectors: $Q_{savingF} = 1{,}5 \cdot 10^3$ kWh
- $h_{energyF}$ is the price of the primary source of energy used in Finland [€/kWh]. As shown in Table V.B.1, the price for electricity in Finland is: $h_{energyF}$ = 0,1192 €/kWh.

Then, substituting these values in Equation 5.5-1, the following expression is obtained:

$$I_{allowedF} = \frac{Q_{savingF} \cdot h_{energyF}}{CRF} = \frac{1{,}5 \cdot 10^3 \cdot 0{,}1192}{0{,}07} = 2.554{,}29€$$

Equation 5.5-2

In short, the allowed investment in Finland is: $\boldsymbol{I_{allowedF}}$ **= 2.554,29€.**

5.5.2 Economical analysis for Spain

For the Spanish virtual house, the solar thermal solution has been: one evacuated tube collector, with which 1,4 MWh, over the 1,7 MWh DHW heating demand, is covered.

Then, the allowed investment for the solar installation in Spain is expressed by the Equation 5.5-3.

$$CRF \cdot I_{allowedS} = Q_{savingS} \cdot h_{energyS}$$

Equation 5.5-3

Where each component is:

- $I_{allowedS}$ is the allowed investment for the Spanish case. It is the solution of the economical analysis.
- $Q_{savingS}$ is the energy saved by the renewable installation in Spain [kWh]. For one evacuated tube collector, the energy saved is: $Q_{savingS} = 1{,}4 \cdot 10^3$ kWh
- $h_{energyF}$ is the price of the primary source of energy used in Spain [€/kWh].

About this, two analyses will be done. One analysis for the case in the simulations, with an electric boiler, where the price per kWh of electricity will be considered. And the other analysis will be performed considering a Natural Gas boiler, as it is the most common source of energy for heating in Spain; therefore for this analysis the price per kWh of Natural Gas will be used.

Electric boiler

The price for electricity in Spain is: $h_{energyS}$*(Electr)* = 0,1696 €/kWh. (Data retrieved from Table V.B.1). So, substituting in Equation 5.5-3:

$$I_{allowedS}(Electr) = \frac{Q_{savingS} \cdot h_{energyS}(Electr)}{CRF} = \frac{1{,}4 \cdot 10^3 \cdot 0{,}1696}{0{,}07} = 3.392€$$

Equation 5.5-4

Natural Gas boiler

The price for electricity in Spain is: $h_{energyS}$*(NatGas)* = 0,0506 €/kWh. (Data retrieved from Table V.B.2). So, substituting in Equation 5.5-3:

$$I_{allowedS}(NatGas) = \frac{Q_{savingS} \cdot h_{energyS}(NatGas)}{CRF} = \frac{1{,}4 \cdot 10^3 \cdot 0{,}0506}{0{,}07} = 1.012€$$

Equation 5.5-5

To summarize, the allowed investment in Spain is:

- For electric boiler: ***$I_{allowedS}$* = 3.392€.**
- For Natural Gas boiler: ***$I_{allowedF}$* = 1.012€.**

5.5.3 Economical analysis conclusions

For the same electric boiler, the allowed investment in Finland (2.554,29€) is lower than in Spain (3.392€). This is because of the high prices of electricity in Spain. And this is a disadvantage for Finland, because the Finnish installation will need two collectors, and the Spanish just one, even if it is more expensive because is an evacuated collector.

However, being more realistic, the allowed investment for the Natural Gas boiler in Spain is much lower than for an electric boiler. Then, the decision about installing an evacuated tube collector, due to economical reasons must be considered, as 1.012€ is not a big amount of money.

All in all, this means that if in Spain there were a house with an electric boiler, it would be more interesting to install this thermal solar system, than in the case that in the house there is a Natural Gas boiler. For the Finnish case, it would only be considered the investment in evacuated tube or glazed collectors.

6 Conclusion and future actions

6.1 Conclusions

After all the results have been obtained and the different situations have been analyzed, this thesis has lead to various conclusions, listed below.

Logically, the power needed for DHW heating for the same house, with the same conditions, in Finland is bigger than in Spain. This is due to climatologic reasons, due to the water network temperature and also because the reference value for DHW demand is different in both countries.

The software RETScreen is trustable for analyses of solar thermal installation, and uses real climatic data (provided from NASA).

The tilting with which more solar energy is received is a value lower than the latitude, which was considered the optimal tilting, due to the solar height in the sunnier days (summer). This value is more times lower in Finland than in Spain, because due to the declination, the sun is higher for the same day in summer in Finland than for Spain.

Also, the tilting in Finland must be performed for preferential summer consumption; because if it is done for annual consumption, as for December, January and February the radiation is insignificant, more energy from the sun is not being used optimally.

However, the tilting of the collectors is Spain should be disposed for annual preferential consumption ($\beta = \varphi$) or even winter preferential ($\beta = \varphi + 10º$). Because this way overheating situations in the sunnier months are avoided and more advantage from the solar resource is taken for the months where the demand is higher, that is in winter.

It is interesting to notice that for the same house in both countries, for the same needs, in Finland is needed the double number of collectors than in Spain, due to the climatologic conditions.

Due to economical reasons, as the performance of glazed and evacuated tube collectors in Finland is not so dissimilar, it is preferred the use of glazed collectors; and at least two collectors must be used for fulfilling the DHW demand.

On the other hand, in Spain, the performance of a single evacuated tube collector is comparable to two glazed collectors, so is advisable to install evacuated collectors for an optimal installation, in both energetic and economical ways.

About economical matters, for the same electric boiler, the allowed investment in Finland (2.554,29€) is lower than in Spain (3.392€). This is because of the high prices of electricity in Spain.

However, being more realistic, the allowed investment for the Natural Gas boiler in Spain is much lower than for an electric boiler. Then, the decision about installing an evacuated tube collector, due to economical reasons must be considered, as 1.012€ is not a big amount of money.

All in all, this means that if in Spain there were a house with an electric boiler, it would be more interesting to install this thermal solar system, than in the case that in the house there is a Natural Gas boiler. For the Finnish case, it would only be considered the investment in acquiring evacuated tube or glazed collectors, but the solar installation is recommended. Though, for both cases, the EU directive, and therefore the corresponding national regulations, for obtaining 20% of the overall energy consumption from renewable energies must be considered.

6.2 Future actions

The future projects or analyses that could be done after this thesis are:

- Design and dimension a solar thermal installation in an existing building for DHW in Spain, or in Finland. The study could be done for different kind of buildings.
- Design and dimension a solar thermal installation for DHW and space heating in Spain, or in Finland.
- Analysis of a solar thermal installation for heating and DHW altogether.
- Compare a DHW installation using the same DHW demand values. (i.e. in Spain it was 30 l/day·person, meanwhile in Finland it was 50 l/day.person)
- Comparison of DHW systems for multifamily buildings, or other type of building, in Spain and in Finland.
- Analyze solar thermal installations with another software. For example, based on the f-chart model, more applicable for the Spanish regulations.

References

A Dictionary of Biology. (2004). *Thermophilic.* Retrieved 04 15, 2011, from Encyclopedia.com: http://www.encyclopedia.com/topic/thermophile.aspx

ACRIM. (2011, 01 15). *Active Cavity Radiometer Irradiance Monitor*. Retrieved 03 13, 2011, from ACRIM: http://acrim.com/Index.htm

AEMET. (2010). *Agencia Estatal de Meteorología [National Meteorological Agency]*. Retrieved 05 16, 2011, from http://www.aemet.es/en/portada

Allaby, A., & Allaby, M. (1999). *A Dictionary of Earth Sciences.* Retrieved 04 15, 2011, from Encyclopedia.com: http://www.encyclopedia.com/doc/1O13-tidalheating.html

Allbiz. (n.d.). *Allbiz*. Retrieved 04 03, 2011, from http://www.pk.all-biz.info/: http://www.pk.all-biz.info/buy/goods/?category=1953

Almeco Tinox Solar. (2011). *Products - Solar Absorber*. Retrieved 05 03, 2011, from Almeco Tinox Solar: http://www.almeco-tinox.com/en/products/solar_absorber

Apricus Solar Co. (2007). *NASA Surface Meteorology and Solar Energy Data Set for Renewable Energy Industry Use.* Retrieved 04 27, 2011, from Apricus.com: http://www.apricus.com/html/insolation_levels_europe.htm

Apricus Solar Co. (2010). *Types of Solar Collectors*. Retrieved 04 28, 2011, from Apricus Solar Hot Water: http://www.apricus.com/html/solar_typesofsolar.htm

Cain, F. (2008, 09 26). *Declination of the Sun.* Retrieved 03 18, 2011, from Universe Today: http://www.universetoday.com/18694/declination-of-the-sun/

CENSOLAR. (n.d.). Retrieved 05 09, 2011, from Centro de Estudios de la Energía Solar [Solar Energy Training Centre]: http://www.censolar.es/

Colectores de placa plana [Flat plate colectors]. (2009). Retrieved 04 12, 2011, from Biblioteca sobre Ingeniería Energética [Library about Energy Engineering]: http://es.libros.redsauce.net/index.php?pageID=12

Collins English Dictionary. (2003). Retrieved 05 06, 2011, from http://www.collinslanguage.com/

CTE. (2009, 04). Código Técnico de Edificación - Documento Básico HE [Technical Building Code - Basic Document HE]. *DB HE: Ahorro de Energía [Basic Document HE Energy Savings]* . España.

Departamento de Ingeniería Térmica y Fluidos. (2004). Apuntes de Energías Renovables [Educational material about Renewables Energies]. *Radiación Solar [Solar Radiation] & ACS Solar [Solar Domestic Hot Water]* . Madrid, España: Universidad Carlos III de Madrid, Department of Thermal and Fluid Engineering.

Dol, K., & Haffner, M. (September 2010). *Housing Statistics in the European Union 2010.* Delft University of Technology: OTB Research Institute for the Built Environment.

Duffie, J. A., & Beckman, W. A. (1980). *Solar Engineering of Thermal Processes.* Wiley - Interscience.

Enciclopaedia Britannica. (2011). Retrieved 04 15, 2011, from http://www.britannica.com/

Energiateollisuus. (2011). Retrieved 05 08, 2011, from http://www.energia.fi/EN

European Comissoin. (2011, 02). *Eurostat*. Retrieved 05 06, 2011, from Housing statistics: http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Housing_statistics

European Union - Europe's Energy Portal. (2011). *Europe's Energy Portal*. Retrieved 05 08, 2011, from http://www.energy.eu/

European Union. (2009, 06 05). DIRECTIVE 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. *Official Journal of the European Union* .

Finnish Meteorological Institute. (2011). Retrieved 05 09, 2011, from http://en.ilmatieteenlaitos.fi/

Green Rhino Energy. (2010). *Green Rhino Energy*. Retrieved 04 02, 2011, from http://www.greenrhinoenergy.com/solar/

Hornsberg, C., & Bowden, S. (2010). Retrieved 03 17, 2011, from PVEDUCATION.ORG: http://pvcdrom.pveducation.org/SUNLIGHT/ATMOSP.HTM

Houghton Mifflin Company. (2000). *The American Heritage® Dictionary of the English Language, Fourth Edition.* Retrieved 04 15, 2011, from The Free Dictionary: http://www.thefreedictionary.com/smokestack

IDAE. (2009, 01). Pliego de Condiciones Técnicas de Insatalaciones de Baja Temperatura [Technical conditions for low temperature installations]. España.

IEA/OECD. (2011). *International Energy Agency*. Retrieved 05 08, 2011, from http://www.iea.org/

INE Instituto Nacional de Estadística [National Statistic Institute]. (2009, 06). Encuesta de Hogares y Medio Ambiente [Household and environment survey]. *Cifras INE, Boletín informativo de INE [INE's Newsletter]* .

International Encyclopedia of the Social Sciences. (2008). *Solar Energy.* Retrieved 04 14, 2011, from Encyclopedia.com: http://www.encyclopedia.com/topic/solar_energy.aspx#1

James, J. &. (2005). *Planning and Installing Solar Thermal Systems.* London, UK: Earthscan.

Ma, Y., Li, G., & Tang, R. (2011). Optical performance of vertical axis three azimuth angles tracked solar panels. *Applied Energy* , 8.

Meteotest. (2008, 06). *Meteonorm*. Retrieved 04 02, 2011, from www.meteonorm.com: http://www.meteonorm.com/pages/en/downloads/maps.php

NASA - For Educators. (2011, 03 09). Retrieved 03 11, 2011, from http://www.nasa.gov/audience/foreducators/index.html

NASA & Atmospheric Science Data Center. (2010, 05 04). *NASA Surface meteorology and Solar Energy.* Retrieved from http://eosweb.larc.nasa.gov/sse/

Natural Resources Canada. (2010, 12 15). *RETScreen International*. Retrieved 05 07, 2011, from http://www.retscreen.net/ang/home.php

Pennsylvania Weatherization Providers. (n.d.). *Solar Hot Water Basics*. Retrieved 04 27, 2011, from Solar Retrofits for Weatherization and Remodels: http://www.pasolar.ncat.org/lesson02.php

Philibert, C. (2005). *The present and future use of solar thermal energy.* Retrieved 04 15, 2011, from International Energy Agency, Paris, France: philibert.cedric.free.fr/Downloads/solarthermal.pdf

Prospectly. (2010). Retrieved 03 18, 2011, from http://www.prospectky.com/users/wxman12/images/Wv001.htm

Rabl, A. (1985). *Active Sollar Collectors and Their Applications.* Cary, NC, USA: Oxford University Press.

Rakennetun ympäristön osasto [Built Environment Division.]. (2011). *Suomen rakentamismääräyskokoelma, D3 ja D5 [Building Code of Finland, sections D3 and D5]*. Helsinki: Ympäristöministeriö [Ministry of Environment].

Rockhill, H. P. (1995). Sealed expansion vessels: a review of current practice. *Structural Survey, Vol. 13* , 18-21.

Schutt, A. C. (2003). *"Desalinization" Water:Science and Issues.* Retrieved 04 27, 2011, from Encyclopedia.com: http://www.encyclopedia.com/topic/Desalinization.aspx

Southface Energy Institute. (2011). *How Solar Thermal Works.* Retrieved 04 27, 2011, from Southface Energy Institute.

Statistics: Energy supply, consumption and prices [e-publication]. (2011, 03 29). Retrieved 05 16, 2011, from Statistics Finland: http://www.stat.fi/til/ehkh/index_en.html

SunEarth, Inc. (n.d.). *SunEarth, Inc.* Retrieved 04 27, 2011, from Energy Supermarket: http://shop.solardirect.com/product_info.php?products_id=191

Swain, L. (2003). *Environmental Encyclopedia.* Retrieved 04 15, 2011, from Encyclopedia.com: http://www.encyclopedia.com/topic/Hydrothermal_vents.aspx

The Columbia Encyclopedia, Sixth Edition. (2008). *Polystyrene.* Retrieved 04 27, 2011, from Encyclopedia.com: http://www.encyclopedia.com/topic/polystyrene.aspx

The Columbia Encyclopedia, Sixth Edition. (2008). *Stirling engine.* Retrieved 04 15, 2011, from Encyclopedia.com: http://www.encyclopedia.com/doc/1E1-Stirlingeng.html

The Encyclopedia of Alternative Energy and Sustainable Living. (n.d.). *Solar Energy and Power.* Retrieved 04 27, 2011, from The Encyclopedia of Alternative Energy and Sustainable Living: http://www.daviddarling.info/encyclopedia/U/AE_unglazed_solar_collector.html

The Encyclopedia of Alternative Energy and Sustainable Living. (n.d.). *Unglazed Solar Collector.* Retrieved 04 27, 2011, from The Encyclopedia of Alternative Energy and Sustainable Living: http://www.daviddarling.info/encyclopedia/U/AE_unglazed_solar_collector.html

The Engineering ToolBox. (n.d.). *Dry Bulb, Wet Bulb and Dew Point Temperature.* Retrieved 04 26, 2011, from The Engineering ToolBox: http://www.engineeringtoolbox.com/dry-wet-bulb-dew-point-air-d_682.html

The solar water heater. (2010, 02 21). Retrieved 04 27, 2011, from 1stop How To: http://www.1stop-how-to.com/25/how-to-build-your-own-solar-water-heater/

U.S. Department of Energy. (n.d.). *Solar Water Heaters*. Retrieved 04 28, 2011, from Energy Savers: http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=12850

Vanek, F., & Albright, L. D. (2008). *Energy Systems Engineering : Evaluation and Implementation.* New York, NY, USA: McGraw-Hill Professional Publishing.

World Encyclopedia. (2005). *Mantle.* Retrieved 04 15, 2011, from Encyclopedia.com: http://www.encyclopedia.com/topic/mantle.aspx#4

World of Earth Science. (2003). *Solar Energy.* Retrieved 04 14, 2011, from Encyclopedia.com: http://www.encyclopedia.com/topic/solar_energy.aspx#2

Appendices

[Note: In these appendices, the figures and tables have been numerated separately. In each appendix, or sub-appendix, all the tables will appear first, and secondly, the figures.]

Appendix I: Terms and definitions

3A sun-tracking system: is a system in which the azimuth angle of solar panels is daily adjusted three times at three fixed positions: eastward, southward and westward in the morning, noon, and afternoon, respectively, by rotating solar panels about the vertical axis.

Air mass, *m*: the ratio of the optical thickness of the atmosphere through which beam radiation passes to the optical thickness if the sun were at its zenith

Albedo, ρ: fraction of light that is reflected by a body or surface.

Angle of incidence, θ: is the angle between the beam radiation on a surface, in any orientation, and the normal to that surface

Architectonic integration: collectors involve a double function, energetic and architectonic; further, they substitute conventional constructive elements or are themselves part of architectural composition.

Beam radiation: is the solar radiation received from the sun without having been scattered by the atmosphere

Blackbody: in physics, is a surface that absorbs all radiant energy falling on it. The term arises because incident visible light will be absorbed rather than reflected, and therefore the surface will appear black.

Clearness index, *K*: is defined as the ratio between the observed (global) daily irradiance on earth, H_g, and the daily radiation H_o just outside the atmosphere

Collector superposition: the collectors are placed along the building's shape, without double functionality, as in architectonic integration.

Declination, δ: is the angular position of the sun at solar noon with respect to the plane of the equator

Diffuse Radiation: is the solar radiation received from the sun after its direction has been changed by scattering by the atmosphere.

Domestic Hot Water (DHW): potable water heated for uses other than space heating. It is used for showering, cleaning, etc.

Dry-bulb temperature (T_{db}): usually referred to as air temperature, is basically the ambient air temperature, and is the most common used air property. It is called "Dry Bulb" because the air temperature is indicated by a thermometer not affected by the moisture of the air. Can be measured using a normal thermometer freely exposed to the air but shielded from radiation and moisture.

Dwelling (Spain): The Household's Primary Residence: each room or group of rooms and their outbuildings, occupying the same building or an area structurally separated from it, that are destined for occupation (in view of the way that they were built, refurbished or transformed) by one or more households and that, at the date of the interview, are not being used for other purposes.

Dwelling (Finland): refers to a room or a set of rooms which is intended for year-round habitation. It is furnished with a kitchen, a kitchenette or a cooking area. It has a floor area of at least seven square metres and is furnished with accessories and facilities necessary for occupancy. Every dwelling must have direct access from the street or from a public or communal staircase, etc. A single-family house may be entered through an enclosed porch or veranda. A dwelling is regarded as a separate set of premises constituting a part of a whole comprising two or more dwellings. A dwelling located in a building which has been classified as a “residential centre” is regarded as a normal dwelling if it has more than one room including a kitchen), at least a kitchen or kitchenette, a flush toilet and a shower, bath or indoor sauna.

Dwellings (Eurostat): are buildings that are used entirely or primarily as residences, including any associated structures, such as garages, and all permanent fixtures customarily installed in residences; movable structures, such as caravans, used as principal residences of households are included.

Electromagnetic spectrum: is the entire distribution of electromagnetic radiation according to frequency or wavelength. The electromagnetic spectrum of an object is the characteristic distribution of electromagnetic radiation emitted or absorbed by that particular object.

Eurostat: (Mathematics & Measurements / Statistics) an organization within the European Union that collects and collates statistical information relating to member states Full name Statistical Office of the European Communities.

Extraterrestrial solar radiation or solar constant, G_{sc}: is the energy from the sun, per unit time, received on a unit area of surface perpendicular to the direction of propagation of the radiation, at the earth’s mean distance from the sun, outside the atmosphere.

Heating Value: is a measure of energy released when a fuel is completely burned. Depending on the composition of the fuel (amount of hydrogen) the amount of steam in the combustion products varies. Higher heating value (HHV) is calculated assuming the combustion product is condensed and the steam is converted to water. Lower heating value (LHV) is calculated assuming the combustion product stays in a vapour form. Higher heating value is typically used in Canada and USA, while lower heating value is used in the rest of the world.

Hour angle, ω: is the angular displacement of the sun east or west of the local meridian due to the rotation of the earth on its axis at 15º per hour

Hydrothermal vents: are hot springs located on the ocean floor. The vents spew out water heated by magma, molten rock from below the earth's crust.

Infrared radiation (IF): is the portion of the electromagnetic spectrum that extends from the long wavelength, or red, end of the visible-light range to the microwave range. It is invisible to the eye, although it can be detected as a sensation of warmth on the skin.

Insolation, Irradiation, or Radiant Exposure [J/ m^2]: is the incident energy per unit area on a surface, found by integration of irradiance over a specified time, usually an hour or a day.

Irradiance, G [W/m^2]: is the rate at which radiant energy is incident on a surface, per unit area of surface. It can be beam of diffuse radiation.

Latent heat: characteristic amount of energy absorbed or released by a substance during a change in its physical state that occurs without changing its temperature.

Latitude, φ: is the angular location north or south of the equator, north being positive.

Mantle: Layer of the Earth between the crust and the core, which extends to a depth of 2890km. The mantle forms the greatest bulk of the Earth: 82% of its volume and 68% of its mass.

Reflected radiation: part of the solar radiation that is reflected from the ground to the surface, or collector.

Slope, β: is the angle between the plane surface in question (the collector object of study) and the horizontal.

Smokestack: is a large chimney or vertical pipe through which combustion vapours, gases, and smoke are discharged.

Solar azimuth angle, γ_s. That is the angular displacement from south of the projection of the beam radiation on the horizontal plane.

Solar height, α_s: angular position of the sun referred to the ground, or to the horizontal plane.

Spectrum: in optics, the arrangement according to wavelength of visible, ultraviolet, and infrared light.

Stirling engine: is an external combustion reciprocating engine having an enclosed working fluid that is alternately compressed and expanded to operate a piston, thus converting heat from a variety of sources into mechanical energy. A Stirling engine can use any type of fuel as well as solar energy and heat from the waters of a hot spring. The engine was invented in 1816 by a Scottish minister, Robert Stirling, before the gasoline and diesel engines appeared.

Styrofoam: trade name of foamed polystyrene plastic, which is a polymer of styrene.

Sunspot: vortex of gas on the surface of the Sun associated with strong local magnetic activity.

Surface azimuth angle, γ: is the deviation of the projection on a horizontal plane of the normal to the surface from the local meridian

Thermophilic: Describing an organism that lives and grows optimally at extremely high temperatures, typically over 40°C.

Tidal Heating: is the generation of heat due to friction produced by the strong tidal forces exerted by a very massive parent body on a body moving about it in an elliptical orbit. The intensity of tidal heating is proportional to the square of the orbital eccentricity, being zero in a circular orbit and reaching a maximum in a parabolic orbit, and inversely proportional to the size of the orbit.

Total Solar Radiation: The sum of the beam and the diffuse radiation on a surface

Ultraviolet radiation (UV): is the portion of the electromagnetic spectrum extending from the violet, or short-wavelength, end of the visible light range to the X-ray region; it is undetectable by the human eye.

Useful floor area (Finland): The floor space of a dwelling is located inside the walls enclosing the dwelling. It includes the space for ancillary facilities such as cloakrooms, bathrooms, hobby-rooms, fireplace rooms, indoor saunas, washrooms and dressing rooms, and rooms used as offices, provided that they are used by the employees. The floor space of a dwelling excludes garages, cellars, saunas located in unfurnished basements, unheated storage spaces, balconies, porches, verandas, outer antechambers and non habitable attic-spaces.

Useful floor area (Spain): The useful floor space is defined as the area between the exterior walls of the dwelling, including balconies. It therefore comprises not only the living space, but also the area of corridors, the entrance hall, bathrooms and other parts that are not strictly living spaces.

Visible light: is the portion of the electromagnetic spectrum visible to the human eye. It ranges from the red end to the violet end of the spectrum, with wavelengths from 700 to 400 nanometres.

Zenith Angle, θ_z: the angle subtended by a vertical line to the zenith (i.e., the point directly overhead) and the line of sight to the sun.

Appendix II: Reference tables for shadow losses

These reference tables depend on the tilting angle, β, and the azimuth angle, γ. It must be chosen the one whose situation is more alike than the one that is going to be studied. The columns and rows are related with the portions of Figure II.1, which are identified by a letter and a number (A1, A2,... D14). The number in each cell indicates the percentage of solar global radiation that would be lost if the corresponding portion would be intercepted by an obstacle.

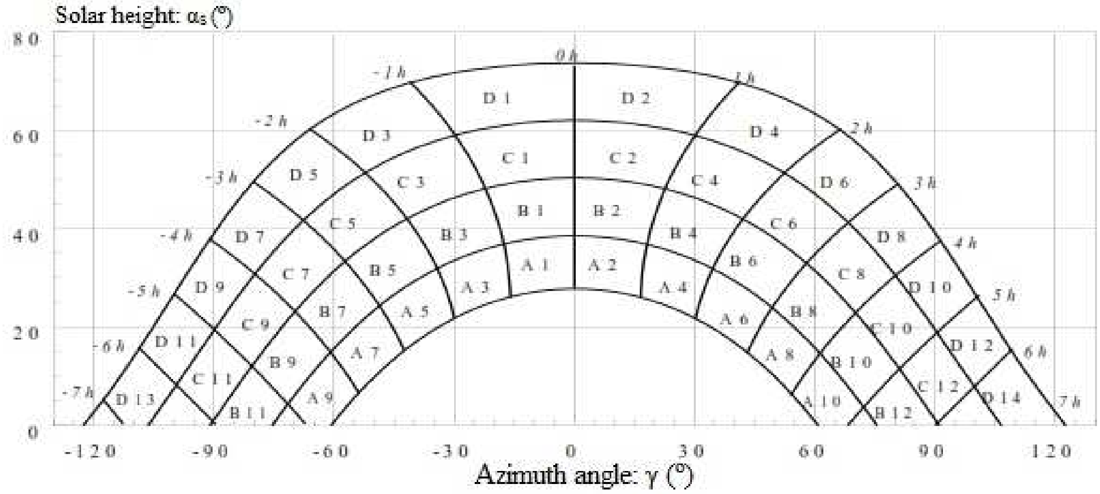


Figure II.1. Sun's path diagram along the year.(CTE, 2009)

About the graph, each portion represent the sun's path during a specific period of time, therefore, it has a particular contribution to the annual global solar irradiation over the surface object of study. Hence, the fact that an obstacle covers one of the portions implies that an amount of radiation is lost, particularly the one which is intercepted by the obstacle. The reference tables are:

Table II.1

	β=35° ; α=0°				β=0° ; α=0°				β=90° ; α=0°				β=35° ; α=30°			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,18	0,00	0,00	0,00	0,15	0,00	0,00	0,00	0,10
11	0,00	0,01	0,12	0,44	0,00	0,01	0,18	1,05	0,00	0,01	0,02	0,15	0,00	0,00	0,03	0,06
9	0,13	0,41	0,62	1,49	0,05	0,32	0,70	2,23	0,23	0,50	0,37	0,10	0,02	0,10	0,19	0,56
7	1,00	0,95	1,27	2,76	0,52	0,77	1,32	3,56	1,66	1,06	0,93	0,78	0,54	0,55	0,78	1,80
5	1,84	1,50	1,83	3,87	1,11	1,26	1,85	4,66	2,76	1,62	1,43	1,68	1,32	1,12	1,40	3,06
3	2,70	1,88	2,21	4,67	1,75	1,60	2,20	5,44	3,83	2,00	1,77	2,36	2,24	1,60	1,92	4,14
1	3,17	2,12	2,43	5,04	2,10	1,81	2,40	5,78	4,36	2,23	1,98	2,69	2,89	1,98	2,31	4,87
2	3,17	2,12	2,33	4,99	2,11	1,80	2,30	5,73	4,40	2,23	1,91	2,66	3,16	2,15	2,40	5,20
4	2,70	1,89	2,01	4,46	1,75	1,61	2,00	5,19	3,82	2,01	1,62	2,26	2,93	2,08	2,23	5,02
6	1,79	1,51	1,65	3,63	1,09	1,26	1,65	4,37	2,68	1,62	1,30	1,58	2,14	1,82	2,00	4,46
8	0,98	0,99	1,08	2,55	0,51	0,82	1,11	3,28	1,62	1,09	0,79	0,74	1,33	1,36	1,48	3,54
10	0,11	0,42	0,52	1,33	0,05	0,33	0,57	1,98	0,19	0,49	0,32	0,10	0,18	0,71	0,88	2,26
12	0,00	0,02	0,10	0,40	0,00	0,02	0,15	0,96	0,00	0,02	0,02	0,13	0,00	0,06	0,32	1,17
14	0,00	0,00	0,00	0,02	0,00	0,00	0,00	0,17	0,00	0,00	0,00	0,13	0,00	0,00	0,00	0,22

(CTE, 2009)

Table II.2

	β=90º ; α=30º				β=35º ; α=60º				β=90º ; α=60º				β=35º ; α= -30º			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
13	0,10	0,00	0,00	0,33	0,00	0,00	0,00	0,14	0,00	0,00	0,00	0,43	0,00	0,00	0,00	0,22
11	0,06	0,01	0,15	0,51	0,00	0,00	0,08	0,16	0,00	0,01	0,27	0,78	0,00	0,03	0,37	1,26
9	0,56	0,06	0,14	0,43	0,02	0,04	0,04	0,02	0,09	0,21	0,33	0,76	0,21	0,70	1,05	2,50
7	1,80	0,04	0,07	0,31	0,02	0,13	0,31	1,02	0,21	0,18	0,27	0,70	1,34	1,28	1,73	3,79
5	3,06	0,55	0,22	0,11	0,64	0,68	0,97	2,39	0,10	0,11	0,21	0,52	2,17	1,79	2,21	4,70
3	4,14	1,16	0,87	0,67	1,55	1,24	1,59	3,70	0,45	0,03	0,05	0,25	2,90	2,05	2,43	5,20
1	4,87	1,73	1,49	1,86	2,35	1,74	2,12	4,73	1,73	0,80	0,62	0,55	3,12	2,13	2,47	5,20
2	5,20	2,15	1,88	2,79	2,85	2,05	2,38	5,40	2,91	1,56	1,42	2,26	2,88	1,96	2,19	4,77
4	5,02	2,34	2,02	3,29	2,86	2,14	2,37	5,53	3,59	2,13	1,97	3,60	2,22	1,60	1,73	3,91
6	4,46	2,28	2,05	3,36	2,24	2,00	2,27	5,25	3,35	2,43	2,37	4,45	1,27	1,11	1,25	2,84
8	3,54	1,92	1,71	2,98	1,51	1,61	1,81	4,49	2,67	2,35	2,28	4,65	0,52	0,57	0,65	1,64
10	2,26	1,19	1,19	2,12	0,23	0,94	1,20	3,18	0,47	1,64	1,82	3,95	0,02	0,10	0,15	0,50
12	1,17	0,12	0,53	1,22	0,00	0,09	0,52	1,96	0,00	0,19	0,97	2,93	0,00	0,00	0,03	0,05
14	0,22	0,00	0,00	0,24	0,00	0,00	0,00	0,55	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,08

(CTE, 2009)

Table II.3

	β=90º ; α= -30º				β=35º ; α= -60º				β=90º ; α= -60º			
	A	B	C	D	A	B	C	D	A	B	C	D
13	0,00	0,00	0,00	0,24	0,00	0,00	0,00	0,56	0,00	0,00	0,00	1,01
11	0,00	0,05	0,60	1,28	0,00	0,04	0,60	2,09	0,00	0,08	1,10	3,08
9	0,43	1,17	1,38	2,30	0,27	0,91	1,42	3,49	0,55	1,60	2,11	4,28
7	2,42	1,82	1,98	3,15	1,51	1,51	2,10	4,76	2,66	2,19	2,61	4,89
5	3,43	2,24	2,24	3,51	2,25	1,95	2,48	5,48	3,36	2,37	2,56	4,61
3	4,12	2,29	2,18	3,38	2,80	2,08	2,56	5,68	3,49	2,06	2,10	3,67
1	4,05	2,11	1,93	2,77	2,78	2,01	2,43	5,34	2,81	1,52	1,44	2,22
2	3,45	1,71	1,41	1,81	2,32	1,70	2,00	4,59	1,69	0,78	0,58	0,53
4	2,43	1,14	0,79	0,64	1,52	1,22	1,42	3,46	0,44	0,03	0,05	0,24
6	1,24	0,54	0,20	0,11	0,62	0,67	0,85	2,20	0,10	0,13	0,19	0,48
8	0,40	0,03	0,06	0,31	0,02	0,14	0,26	0,92	0,22	0,18	0,26	0,69
10	0,01	0,06	0,12	0,39	0,02	0,04	0,03	0,02	0,08	0,21	0,28	0,68
12	0,00	0,01	0,13	0,45	0,00	0,01	0,07	0,14	0,00	0,02	0,24	0,67
14	0,00	0,00	0,00	0,27	0,00	0,00	0,00	0,12	0,00	0,00	0,00	0,36

(CTE, 2009)

Appendix III: Collector types

Tables III.1 - 3 list collector types, typical operating temperatures, current costs and additional comments.

Table III.1. Nontracking collectors.

Collector type	Approximate maximum operating temperature (°C)	Cost ($/m²)	Comments
Shallow solar pond	40–60	160[a] (complete system, including storage for 1 day)	Plastic covers may need to be replaced every 5 yr or so. Needs sunny climate for good performance.
Deep solar pond (salt gradient)	40–90	30–60[b] (includes storage)	Collector and longterm storage in one unit. For seasonal storage, depth should be about 3 m. Low cost, but low efficiency (10%–20%).
Flat plate			
(a) Conventional design	40–80	150–300[c,d]	Best known and most developed of all collector types.
(b) Made of plastic	30–60	70–100[c,d]	
(c) Unglazed	10–20 above ambient	70–100[c,d]	
Nonevacuated CPC fixed-tilt or summer-to-winter tilt adjustment	80–120	150[c,d]	—
Evacuated tubes (with reflector enhancement; e.g., CPC)	100–200	250–300[c,d]	Many opportunities for cost reduction by mass production and for performance improvements through R&D.

[a]Cost estimate in 1980. Personal communication, Solar Energy Group, Lawrence Livermore Laboratory, Livermore, CA 94550.
[b]Costs of solar ponds are very site-specific (e.g., salt may be free, liner may not be needed, etc.). A 3-m deep salt-gradient solar pond was built in Miamisburg, OH for 35 $/m² in 1978.
[c]*Solar Products Specifications Guide*. 1983. Published annually by *Solar Age Magazine*, Church Hill, Harrisville, NH 03450.
[d]For some collectors several manufacturers are in the market, with a wide spread in quality and price (not always correlated). Some models exceed the price range indicated here.

(Rabl, 1985)

Table III.2. One-axis tracking collectors.

Collector type	Approximate maximum operating temperature (°C)	Cost ($/m^2)	Comments
Inflated cylindrical reflector	140	50–70[a]	Does not need continuous tracking, but does require weekly tilt adjustments; plastic cover may need to be replaced every 5 yr or so.
Parabolic trough	300	150–300[b,c]	Continuous accurate tracking; sensitive to dirt.
Line-focus Fresnel reflector	250	—	May combine advantages of parabolic trough and of central receiver for temperatures below 250°C.
Fixed line-focus reflector with tracking receiver	250	—	Problems with dirt accumulation on reflectors.

[a]Cost estimate in 1980. Personal communication, Solar Energy Group, Lawrence Livermore Laboratory, Livermore, CA 94550.
[b]*Solar Products Specifications Guide.* 1983. Published annually by *Solar Age Magazine*, Church Hill, Harrisville, NH 03450.
[c]For some collectors several manufacturers are in the market, with a wide spread in quality and price (not always correlated). Some models exceed the price range indicated here.

(Rabl, 1985)

Table III.3. Two-axis tracking collectors.

Collector type	Approximate maximum operating temperature (°C)	Cost ($/m^2)	Comments
Parabolic dish or point-focus Fresnel lens	1500 (possibly more)	—	Good if energy can be used directly in focal zone (e.g., photovoltaics or solar thermal power); otherwise, transporting heat to point of use is problematic.
Central receivers	1000 (possibly more)	492[a]	Optical transport of energy.
		355[b] plus tower[c]	
Fixed-hemispherical reflector, tracking receiver	400	—	Problems with heat transport to point of use, and with dirt accumulation on reflector.

[a]Average cost of heliostats for Barstow solar power plant, in 1980 [Battleson, 1981].
[b]Incremental cost of heliostats for Barstow after tooling costs, etc. have been paid, in 1980 [Battleson, 1981].
[c]Cost of tower is estimated to be approximately 10% of heliostat cost.

(Rabl, 1985)

Appendix IV: Climatic and basic data

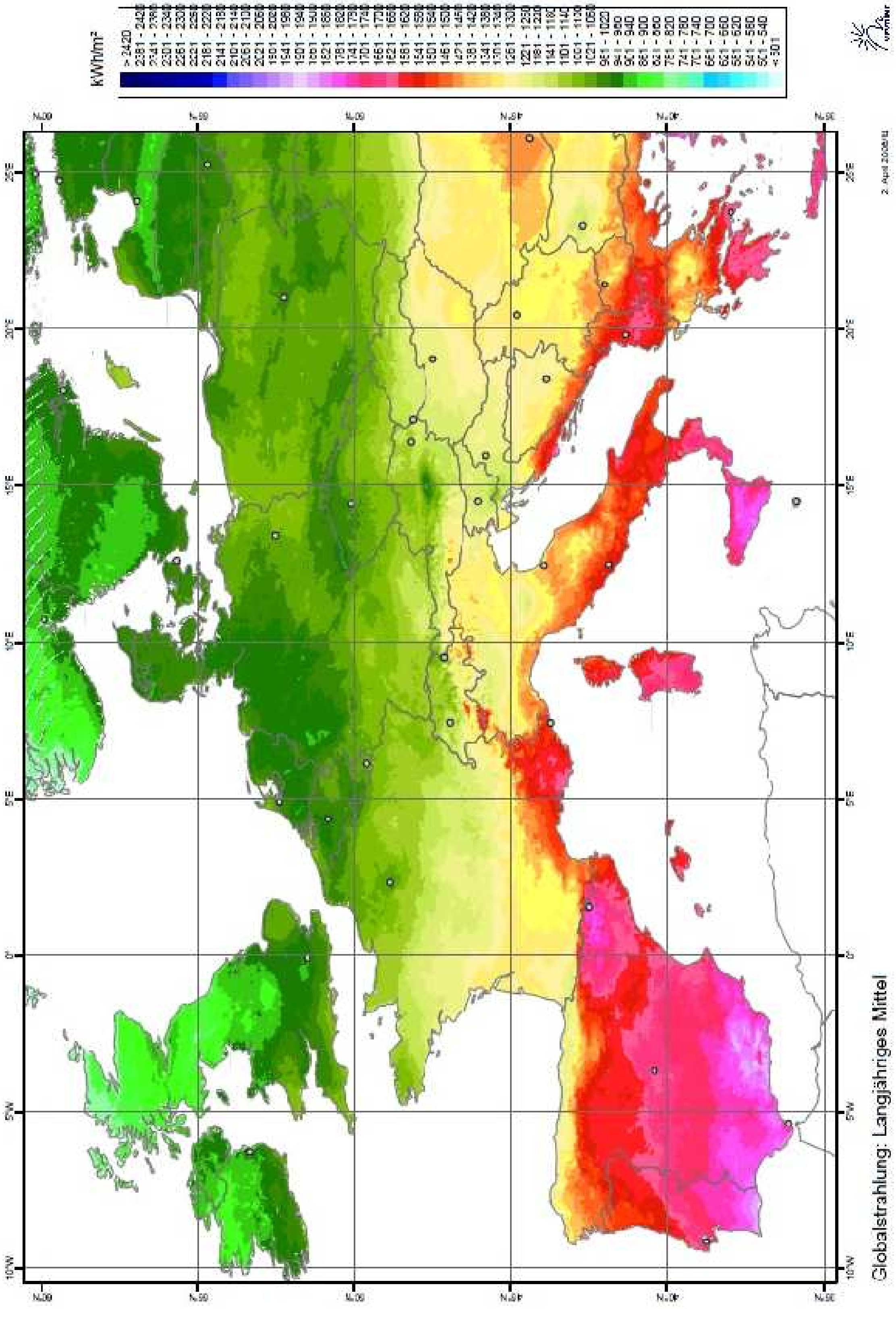
Appendix IV.A: Data in Europe

Table IV.A.1. Average daily insolation levels in Europe, 10 years average [kWh/m²/day]

Country	State/City	Latitude	Longitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year Avg
AT	Vienna	48° 13' N	16° 22' E	1.10	1.81	2.80	3.76	4.76	5.12	5.72	4.98	3.68	2.15	1.28	0.93	**3.52**
BE	Bruxelles	50° 45' N	4° 30' E	0.74	1.31	2.29	3.68	4.67	4.48	4.82	4.20	2.86	1.73	0.92	0.56	**3.02**
BG	Sofija	42° 40' N	23° 18' E	1.5	2.04	2.97	4.05	5	5.8	6.29	5.68	4.46	2.75	1.62	1.27	**3.99**
CY	Limassol	34° 40' N	33° 03' E	2.52	3.26	4.54	6.00	6.85	7.81	7.80	7.18	6.11	4.43	3.02	2.31	**5.61**
CR	Zagreb	45° 29' N	15° 35' E	1.30	2.00	2.94	3.91	5.03	5.37	5.93	5.19	3.94	2.39	1.39	1.09	**3.72**
DE	Hamburg	53° 33' N	9° 59' E	0.54	1.11	2.09	3.68	4.86	4.47	4.47	3.89	2.59	1.48	0.69	0.40	**2.52**
DE	Munich	48° 05' N	11° 23' E	1.05	1.80	2.82	3.95	4.84	4.65	5.14	4.46	3.20	2.00	1.02	0.79	**2.98**
ES	Madrid	40° 25' N	3° 41' W	1.93	2.75	4.09	4.83	5.85	6.52	7.11	6.30	4.91	3.07	1.97	1.59	**4.62**
ES	Malaga	36° 42' N	4° 42' W	2.52	3.24	4.51	5.40	6.35	7.09	7.64	6.81	5.39	3.70	2.58	2.14	**5.16**
ES	Barcelona	41° 24' N	2° 9' E	1.89	2.71	3.97	4.99	5.82	6.56	7.01	6.07	4.72	3.11	2.04	1.70	**4.60**
ES	Alicante	38° 40' N	0° 30' W	2.23	3.02	4.26	5.39	6.13	6.89	7.34	6.53	5.11	3.45	2.34	1.94	**4.94**
FX	Lyon	45° 46' N	4° 50' E	1.26	1.97	3.02	4.08	4.97	5.40	6.03	5.23	3.93	2.27	1.43	1.08	**3.74**
FX	Paris	48° 52' N	2° 20' E	0.89	1.62	2.62	3.95	4.90	4.83	5.35	4.61	3.33	2.00	1.12	0.72	**3.34**
FX	Toulouse	43° 37' N	1° 26' E	1.39	2.14	3.19	4.03	4.82	5.16	5.86	5.07	4.09	2.48	1.58	1.25	**3.75**
GR	Athens	38° N	23° 43' E	2.00	2.52	3.67	5.21	6.38	7.52	7.61	6.91	5.57	3.50	2.16	1.63	**4.56**
HU	Budapest	47° 30' N	19° 3' E	1.00	1.71	2.76	3.90	5.03	5.30	5.62	4.84	3.57	2.24	1.17	0.88	**3.17**
IE	Dublin	53° 20' N	6° 15' W	0.56	1.07	1.97	3.32	4.40	4.30	4.30	3.40	2.69	1.43	0.77	0.43	**2.39**
IT	Milan	45° 28' N	9° 12' E	1.27	1.89	2.91	3.65	4.84	5.36	5.97	5.21	3.91	2.40	1.42	1.08	**3.33**
IT	Rome	41° 53' N	12° 30' E	1.78	2.52	3.71	4.87	5.98	6.84	7.08	6.34	4.83	3.08	1.98	1.56	**4.21**
NL	Amsterdam	52° 21' N	4° 54' E	0.61	1.21	2.27	3.76	4.88	4.73	4.78	4.13	2.80	1.60	0.78	0.45	**2.67**
NO	Oslo	59° 56' N	10° 44' E	0.3	0.87	1.68	3.12	4.65	4.84	4.59	3.36	2.22	1.02	0.42	0.19	**2.27**
RO	Bucharest	44° 26' N	26° 06' E	1.36	1.94	2.91	3.94	5.03	5.6	6.15	5.53	4.15	2.59	1.37	1.1	**3.47**
PT	Lisboa	38° 42' N	9° 11' W	2.27	2.99	4.3	5.15	6.13	6.46	6.89	6.33	5.11	3.44	2.27	1.84	**4.43**
PT	Oviedo	43° 21' N	5° 50' W	1.67	2.29	3.44	4.59	5.56	6.32	6.86	5.95	4.51	2.71	1.77	1.46	**3.93**
UA	Odessa	46° 30' N	30° 46' E	1.08	1.78	2.68	3.87	5.4	5.7	6.39	5.63	3.96	2.45	1.06	0.87	**3.41**
UK	Edinburgh	55° 55' N	3' 10' W	0.44	0.94	1.86	3.18	4.33	4.34	4.13	3.41	2.43	1.2	0.59	0.32	**2.26**
UK	London	51° 32' N	0° 5' W	0.67	1.26	2.22	3.48	4.54	4.51	4.74	4.01	2.86	1.65	0.89	0.52	**2.61**
SZ	Bern	46° 57' N	7° 26' E	1.1	1.77	2.74	3.6	4.7	5.07	5.68	4.95	3.66	2.18	1.26	0.92	**3.14**
SZ	Lausanne	46° 32' N	6° 39' E	1.10	1.81	2.80	3.76	4.76	5.12	5.72	4.98	3.68	2.15	1.28	0.93	**3.17**
YU	Beograd	44° 50' N	20° 30' E	1.29	1.89	2.92	3.86	4.88	5.45	6	5.3	4.05	2.5	1.4	1.11	**3.39**

(Apricus Solar Co., 2007)

Figure IV.A.1. Annual global irradiance in Europe.



(Meteotest, 2008)

Appendix IV.B: Data in Finland

Table IV.B.1. Different temperature values measured in Jyväskylä (1971-2000).

JYVÄSKYLÄ 1971-2000											
	Lämpötila °C Temperature °C					Lämpöt.päivät kpl/no T-days		SADE (mm) Precip.		LUMI (cm) Snow	
Kk Month	Keskimääräiset Mean	Max	Min	Abs. max	Abs. min	T max > 25°C	T min < 0°C	Keskim. Avg	Max per day	15.pvä 15 th	Viim. Last
1	-8,5	-5,3	-12,3	7,8	-38,5		30	43	82	31	38
2	-8,7	-5,0	-12,9	11,0	-37,1		27	31	85	42	45
3	-4,0	0,2	-8,4	14,0	-31,5		28	37	70	45	41
4	1,4	6,0	-3,2	22,6	-19,5		22	37	79	22	4
5	8,7	14,5	2,4	28,0	-9,0	1	9	38	79		
6	14,0	19,3	8,1	31,3	-2,6	4	1	59	157		
7	16,0	21,3	10,4	33,3	1,1	6		79	146		
8	13,7	18,4	8,9	29,1	-2,2	2		88	182		
9	8,2	12,3	4,2	23,5	-9,2		5	63	101		
10	3,2	6,0	0,3	16,5	-18,8		14	60	118		2
11	-2,2	0,2	-4,9	10,3	-27,2		23	57	114	5	13
12	-6,4	-3,5	-10,0	10,7	-34,8		29	47	94	19	24
Vuosi Year	3,0	7,0	-1,4	33,3	-38,5	13	188	638			

(Finnish Meteorological Institute, 2011)

Table IV.B.2. Wind distribution in Finland.

MUSTASAARI VALASSAARET																		
	Tuulien jakautuminen - Wind distribution																	
KK	N		NE		E		SE		S		SW		W		NW		tyyni calm	ka mean
month	m/s	%	m/s	%	m/s	%	m/s	%	m/s	%	m/s	%	m/s	%	m/s	%	%	m/s
1	8,5	12	7,5	9	5,8	8	4,8	13	7,3	21	8,0	15	7,4	14	7,6	9	1	7,1
2	8,0	10	7,8	11	4,9	7	4,4	10	7,0	25	6,9	17	7,1	12	6,7	8	0	6,7
3	7,7	10	6,6	13	4,5	9	4,5	9	6,8	30	6,2	15	6,5	9	6,5	5	1	6,3
4	7,3	13	7,1	18	4,4	8	3,9	7	6,3	22	5,3	14	5,5	10	5,8	6	1	5,9
5	6,1	11	6,3	21	3,9	8	3,9	4	6,3	22	5,3	17	5,1	10	5,0	6	0	5,6
6	6,0	13	5,8	18	3,9	9	3,4	3	6,2	23	5,3	16	5,0	10	5,2	8	1	5,4
7	5,9	13	5,6	18	3,8	8	3,7	5	5,6	20	4,8	16	4,8	10	5,0	8	1	5,1
8	6,9	13	6,3	16	4,4	7	3,7	7	5,4	18	5,2	15	5,3	12	6,2	9	1	5,5
9	8,0	12	6,8	11	5,3	8	4,0	9	6,1	21	6,2	15	6,8	13	7,6	10	1	6,4
10	9,0	12	9,1	8	7,3	7	5,0	12	6,6	21	7,1	16	7,6	14	8,4	10	1	7,3
11	9,3	13	8,6	7	7,3	7	5,4	15	7,0	18	8,0	15	7,7	14	8,2	10	0	7,6
12	9,0	12	9,1	7	6,8	8	4,9	13	7,3	19	8,1	15	8,0	14	8,2	11	0	7,6
vuosi year	7,6	12	7,2	13	5,2	8	4,3	9	6,5	22	6,4	15	6,4	12	6,7	8	1	6,4

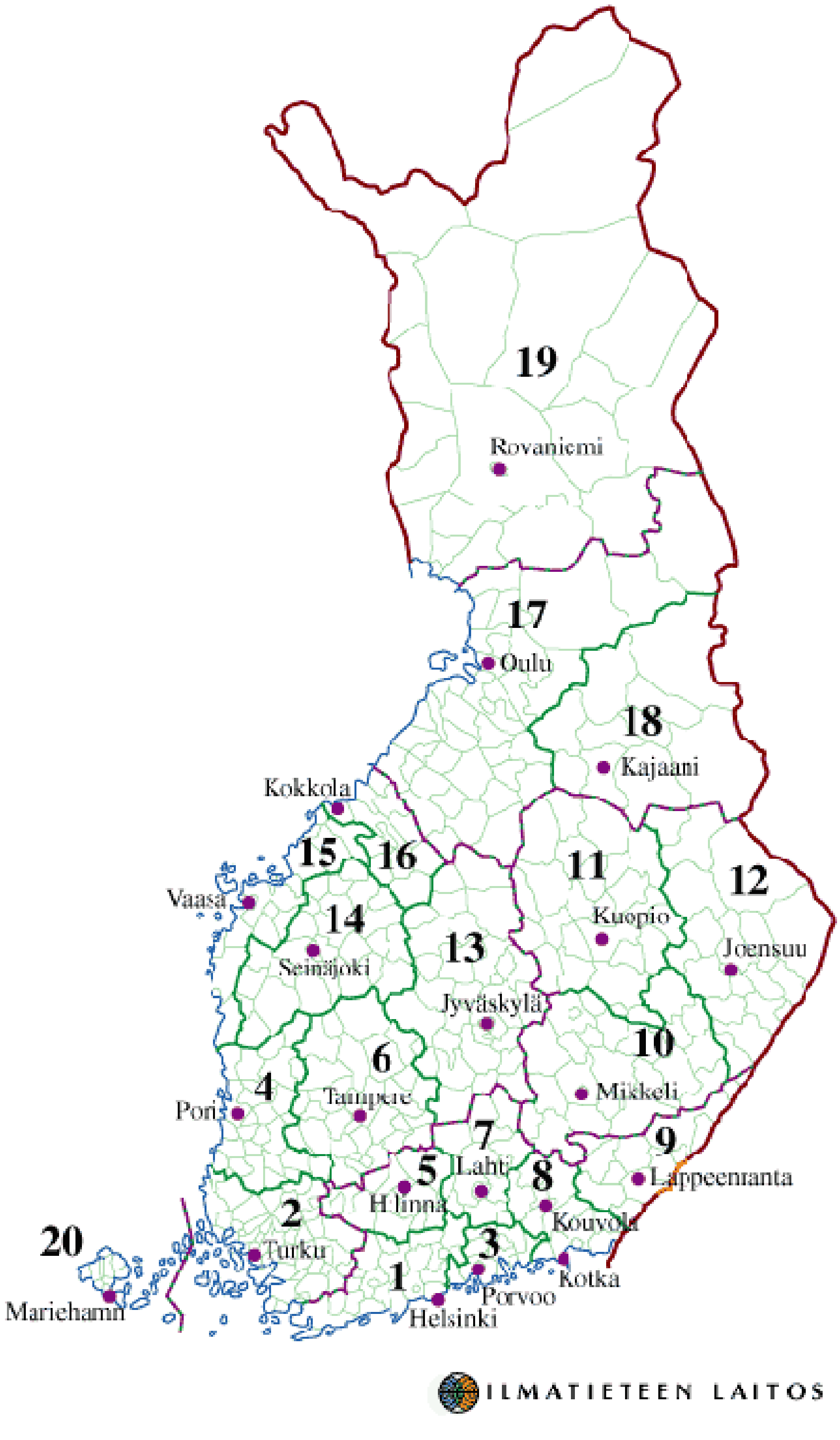
(Finnish Meteorological Institute, 2011)

Table IV.B.3. Daylight in Finland throughout the year

	Helsinki	Southern Finland		**Jyväskylä**	Middle part of Finland		**Sodankylä**	Lappland	
	nousee	laskee	pituus	nousee	laskee	pituus	nousee	laskee	pituus
pvm / month	sunrise h:min	sunset h:min	lenght of day h:min	sunrise h:min	sunset h:min	lenght of day h:min	sunrise h:min	sunset h:min	lenght of day h:min
1.1. /1st Jan	9:24	15:24	6:00	9:43	14:59	5:16	11:31	13:04	1:33
16.1.	9:08	15:55	6:47	9:22	15:32	6:10	10:30	14:18	3:48
1.2. / 1st Feb	8:36	16:33	7:57	8:45	16:17	7:32	9:25	15:30	6:05
15.2.	7:59	17:10	9:11	8:05	16:59	8:54	8:29	16:28	7:59
1.3. / 1st Mar	7:20	17:46	10:26	7:21	17:39	10:18	7:32	17:21	9:49
16.3.	6:35	18:24	11:49	6:33	18:20	11:47	6:31	18:15	11:44
1.4. / 1st Apr	6:46	20:03	13:17	6:40	20:04	13:24	6:26	20:12	13:46
16.4.	6:01	20:41	14:40	5:51	20:45	14:54	5:23	21:06	15:43
1.5. / 1stMay	5:18	21:18	16:00	5:03	21:27	16:24	4:19	22:06	17:47
16.5.	4:40	21:55	17:15	4:20	22:09	17:49	3:09	23:15	20:06
1.6. / 1st Jun	4:08	22:29	18:21	3:42	22:49	19:07	-	-	**24 h**
16.6.	3:54	22:48	18:54	3:24	23:12	19:48	-	-	**24 h**
1.7. / 1stJul	4:00	22:47	18:47	3:30	23:11	19:41	-	-	**24 h**
16.7.	4:24	22:27	18:03	3:59	22:46	18:47	2:00	0:40	22:40
1.8. / 1st Aug	4:59	21:52	16:53	4:40	22:04	17:24	3:37	22:59	19:22
16.8.	5:35	21:12	15:37	5:24	21:19	15:55	4:45	21:52	17:07
1.9./ 1st Sep	6:14	20:25	14:11	6:05	20:28	14:23	5:41	20:44	15:03
16.9.	6:49	19:39	12:50	6:44	19:38	12:54	6:34	19:42	13:08
1.10. / 1st Oct	7:25	18:54	11:29	7:23	18:49	11:26	7:25	18:40	11:15
16.10.	8:02	18:09	10:07	8:04	18:00	9:56	8:18	17:40	9:22
1.11. / 1st Nov	7:42	16:24	8:42	7:49	16:12	8:23	8:18	15:35	7:17
16.11.	8:21	15:48	7:27	8:32	15:31	6:59	9:21	14:34	5:13
1.12. / 1st Dec	8:56	15:22	6:26	9:12	15:00	5:48	10:31	13:34	3:03
16.12.	9:20	15:12	5:52	9:39	14:46	5:07	11:46	12:32	0:46
31.12./last Dec	9:25	15:22	5:57	9:44	14:55	5:11	11:36	12:58	1:22

(Finnish Meteorological Institute, 2011)

Figure IV.B.1. Regions in Finland.



1. Uusimaa
2. Varsinais-Suomi
3. Itä-Uusimaa
4. Satakunta
5. Kanta-Häme
6. Pirkanmaa
7. Päijät-Häme
8. Kymenlaakso
9. South Karelia
10. Etelä-Savo
11. Pohjois-Savo
12. North Karelia
13. Central Finland
14. South Ostrobothnia
15. Ostrobothnia
16. Central Ostrobothnia
17. North Ostrobothnia
18. Kainuu
19. Lapland
20. Åland

(Finnish Meteorological Institute, 2011)

Appendix IV.C: Data in Spain

Table IV.C.1 Solar irradiation in cities of Spain over a horizontal surface [MJ/m^2].

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1	ÁLAVA	4,6	6,9	11,2	13	14,8	16,6	18,1	17,3	14,3	9,5	5,5	4,1	11,3
2	ALBACETE	6,7	10,5	15	19,2	21,2	25,1	26,7	23,2	18,8	12,4	8,4	6,4	16,1
3	ALICANTE	8,5	12	16,3	18,9	23,1	24,8	25,8	22,5	18,3	13,6	9,8	7,6	16,8
4	ALMERÍA	8,9	12,2	16,4	19,6	23,1	24,6	25,3	22,5	18,5	13,9	10	8	16,9
5	ASTURIAS	5,3	7,7	10,6	12,2	15	15,2	16,8	14,8	12,4	9,8	5,9	4,6	10,9
6	ÁVILA	6	9,1	13,5	17,7	19,4	22,3	26,3	25,3	18,8	11,2	6,9	5,2	15,1
7	BADAJOZ	6,5	10	13,6	18,7	21,8	24,6	25,9	23,8	17,9	12,3	8,2	6,2	15,8
8	BALEARES	7,2	10,7	14,4	16,2	21	22,7	24,2	20,6	16,4	12,1	8,5	6,5	15
9	BARCELONA	6,5	9,5	12,9	16,1	18,6	20,3	21,6	18,1	14,6	10,8	7,2	5,8	13,5
10	BURGOS	5,1	7,9	12,4	16	18,7	21,5	23	20,7	16,7	10,1	6,5	4,5	13,6
11	CÁCERES	6,8	10	14,7	19,6	22,1	25,1	28,1	25,4	19,7	12,7	8,9	6,6	16,6
12	CÁDIZ	8,1	11,5	15,7	18,5	22,2	23,8	25,9	23	18,1	14,2	10	7,4	16,5
13	CANTABRIA	5	7,4	11	13	16,1	17	18,4	15,5	13	9,5	5,8	4,5	11,3
14	CASTELLÓN	8	12,2	15,5	17,4	20,6	21,4	23,9	19,5	16,6	13,1	8,6	7,3	15,3
15	CEUTA	8,9	13,1	18,6	21	24,3	26,7	26,8	24,3	19,1	14,2	11	8,6	18,1
16	CIUDAD REAL	7	10,1	15	18,7	21,4	23,7	25,3	23,2	18,8	12,5	8,7	6,5	15,9
17	CÓRDOBA	7,2	10,1	15,1	18,5	21,8	25,9	28,5	25,1	19,9	12,6	8,6	6,9	16,7
18	LA CORUÑA	5,4	8	11,4	12,4	15,4	16,2	17,4	15,3	13,9	10,9	6,4	5,1	11,5
19	CUENCA	5,9	8,8	12,9	17,4	18,7	22	25,6	22,3	17,5	11,2	7,2	5,5	14,6
20	GERONA	7,1	10,5	14,2	15,9	18,7	19	22,3	18,5	14,9	11,7	7,8	6,6	13,9
21	GRANADA	7,8	10,8	15,2	18,5	21,9	24,8	26,7	23,6	18,8	12,9	9,6	7,1	16,5
22	GUADALAJARA	6,5	9,2	14	17,9	19,4	22,7	25	23,2	17,8	11,7	7,8	5,6	15,1
23	GUIPÚZCOA	5,5	7,7	11,3	11,7	14,6	16,2	16,1	13,6	12,7	10,3	6,2	5	10,9
24	HUELVA	7,6	11,3	16	19,5	24,1	25,6	28,7	25,6	21,2	14,5	9,2	7,5	17,6
25	HUESCA	6,1	9,6	14,3	18,7	20,3	22,1	23,1	20,9	16,9	11,3	7,2	5,1	14,6
26	JAÉN	6,7	10,1	14,4	18	20,3	24,4	26,7	24,1	19,2	11,9	8,1	6,5	15,9
27	LEÓN	5,8	8,7	13,8	17,2	19,5	22,1	24,2	20,9	17,2	10,4	7	4,8	14,3
28	LÉRIDA	6	9,9	18	18,8	20,9	22,6	23,8	21,3	16,8	12,1	7,2	4,8	15,2
29	LUGO	5,1	7,6	11,7	15,2	17,1	19,5	20,2	18,4	15	9,9	6,2	4,5	12,5
30	MADRID	6,7	10,6	13,6	18,8	20,9	23,5	26	23,1	16,9	11,4	7,5	5,9	15,4
31	MÁLAGA	8,3	12	15,5	18,5	23,2	24,5	26,5	23,2	19	13,6	9,3	8	16,8
32	MELILLA	9,4	12,6	17,2	20,3	23	24,8	24,8	22,6	18,3	14,2	10,9	8,7	17,2
33	MURCIA	10,1	14,8	16,6	20,4	24,2	25,6	27,7	23,5	18,6	13,9	9,8	8,1	17,8
34	NAVARRA	5	7,4	12,3	14,5	17,1	18,9	20,5	18,2	16,2	10,2	6	4,5	12,6
35	ORENSE	4,7	7,3	11,3	14	16,2	17,6	18,3	16,6	14,3	9,4	5,6	4,3	11,6
36	PALENCIA	5,3	9	13,2	17,5	19,7	21,8	24,1	21,6	17,1	10,9	6,6	4,6	14,3
37	LAS PALMAS	11,2	14,2	17,8	19,6	21,7	22,5	24,3	21,9	19,8	15,1	12,3	10,7	17,6
38	PONTEVEDRA	5,5	8,2	13	15,7	17,5	20,4	22	18,9	15,1	11,3	6,8	5,5	13,3
39	LA RIOJA	5,6	8,8	13,7	16,6	19,2	21,4	23,3	20,8	16,2	10,7	6,8	4,8	14
40	SALAMANCA	6,1	9,5	13,5	17,1	19,7	22,8	24,6	22,6	17,5	11,3	7,4	5,2	14,8
41	S.C. TENERIFE	10,7	13,3	18,1	21,5	25,7	26,5	29,3	26,6	21,2	16,2	10,8	9,3	19,1
42	SEGOVIA	5,7	8,8	13,4	18,4	20,4	22,6	25,7	24,9	18,8	11,4	6,8	5,1	15,2
43	SEVILLA	7,3	10,9	14,4	19,2	22,4	24,3	24,9	23	17,9	12,3	8,8	6,9	16
44	SORIA	5,9	8,7	12,8	17,1	19,7	21,8	24,1	22,3	17,5	11,1	7,6	5,6	14,5
45	TARRAGONA	7,3	10,7	14,9	17,6	20,2	22,5	23,8	20,5	16,4	12,3	8,8	6,3	15,1
46	TERUEL	6,1	8,8	12,9	16,7	18,4	20,6	21,8	20,7	16,9	11	7,1	5,3	13,9
47	TOLEDO	6,2	9,5	14	19,3	21	24,4	27,2	24,5	18,1	11,9	7,6	5,6	15,8
48	VALENCIA	7,6	10,6	14,9	18,1	20,6	22,8	23,8	20,7	16,7	12	8,7	6,6	15,3
49	VALLADOLID	5,5	8,8	13,9	17,2	19,9	22,6	25,1	23	18,3	11,2	6,9	4,2	14,7
50	VIZCAYA	5	7,1	10,8	12,7	15,5	16,7	17,9	15,7	13,1	9,3	6	4,6	11,2
51	ZAMORA	5,4	8,9	13,2	17,3	22,2	21,6	23,5	22	17,2	11,1	6,7	4,6	14,5
52	ZARAGOZA	6,3	9,8	15,2	18,3	21,8	24,2	25,1	23,4	18,3	12,1	7,4	5,7	15,6

(CENSOLAR)

Table IV.C.2.Geographical data of main cities of Spain.

		Elevation	Latitude	Longitude		Historical Tmin
1	ÁLAVA	542	42,9	2,7	W	-18
2	ALBACETE	686	39	1,8	W	-23
3	ALICANTE	7	38,4	0,5	W	-5
4	ALMERÍA	65	36,9	2,4	W	-1
5	ASTURIAS	232	43,4	5,8	W	-11
6	ÁVILA	1126	40,7	4,9	W	-21
7	BADAJOZ	186	38,9	7	W	-6
8	BALEARES	28	39,6	2,6	E	-4
9	BARCELONA	95	41,4	2,2	E	-7
10	BURGOS	929	42,3	3,7	W	-18
11	CÁCERES	459	39,5	6,4	W	-6
12	CÁDIZ	28	36,5	6,3	W	-2
13	CANTABRIA	69	43,5	3,8	W	-4
14	CASTELLÓN	27	40	0	W	-8
15	CEUTA	206	35,9	5,3	W	-1
16	CIUDAD REAL	628	39	3,9	W	-10
17	CÓRDOBA	128	37,9	4,8	W	-6
18	LA CORUÑA	54	43,4	8,4	W	-9
19	CUENCA	949	40,1	2,1	W	-21
20	GERONA	95	42	2,7	E	-11
21	GRANADA	775	37,2	3,7	W	-13
22	GUADALAJARA	685	40,6	3,2	W	-14
23	GUIPÚZCOA	181	43,3	2	W	-12
24	HUELVA	4	37,3	6,9	W	-6
25	HUESCA	488	42,1	0,4	W	-14
26	JAÉN	586	37,8	3,8	W	-8
27	LEÓN	908	42,6	5,6	W	-18
28	LÉRIDA	323	41,7	1,2	E	-11
29	LUGO	465	43	7,6	W	-8
30	MADRID	667	40,4	3,7	W	-16
31	MÁLAGA	40	36,7	4,4	W	-4
32	MELILLA	47	35,3	3	W	-1
33	MURCIA	42	38	1,1	W	-5
34	NAVARRA	449	42,8	1,6	W	-16
35	ORENSE	139	42,3	7,8	W	-8
36	PALENCIA	734	42	4,5	W	-14
37	LAS PALMAS	6	28,2	15,4	W	6
38	PONTEVEDRA	19	42,4	8,6	W	-4
39	LA RIOJA	380	42,5	2,4	W	-12
40	SALAMANCA	803	41	5,6	W	-16
41	STA. C. DE TENERIFE	37	28,5	16,2	W	3
42	SEGOVIA	1002	41	4,1	W	-17
43	SEVILLA	30	37,4	6	W	-6
44	SORIA	1063	41,8	2,5	W	-16
45	TARRAGONA	60	41,1	1,2	E	-7
46	TERUEL	915	40,4	1,1	W	-14
47	TOLEDO	540	39,9	4	W	-9
48	VALENCIA	10	39,5	0,4	W	-8
49	VALLADOLID	694	41,7	4,7	W	-16
50	VIZCAYA	32	43,3	3	W	-8
51	ZAMORA	649	41,5	5,7	W	-14
52	ZARAGOZA	200	41,7	0,9	W	-11

(CENSOLAR)

Table IV.C.3.Water network temperature of main cities of Spain [ºC].

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1	ÁLAVA	5	6	8	10	11	12	13	12	11	10	8	5	9,3
2	ALBACETE	5	6	8	10	11	12	13	12	11	10	8	5	9,3
3	ALICANTE	8	9	11	13	14	15	16	15	14	13	11	8	12,3
4	ALMERÍA	8	9	11	13	14	15	16	15	14	13	11	8	12,3
5	ASTURIAS	6	7	9	11	12	13	14	13	12	11	9	6	10,3
6	ÁVILA	4	5	7	9	10	11	12	11	10	9	7	4	8,3
7	BADAJOZ	6	7	9	11	12	13	14	13	12	11	9	6	10,3
8	BALEARES	8	9	11	13	14	15	16	15	14	13	11	8	12,3
9	BARCELONA	8	9	11	13	14	15	16	15	14	13	11	8	12,3
10	BURGOS	4	5	7	9	10	11	12	11	10	9	7	4	8,3
11	CÁCERES	6	7	9	11	12	13	14	13	12	11	9	6	10,3
12	CÁDIZ	8	9	11	13	14	15	16	15	14	13	11	8	12,3
13	CANTABRIA	8	9	11	13	14	15	16	15	14	13	11	8	12,3
14	CASTELLÓN	8	9	11	13	14	15	16	15	14	13	11	8	12,3
15	CEUTA	8	9	10	12	13	13	14	13	13	12	11	8	11,3
16	CIUDAD REAL	5	6	8	10	11	12	13	12	11	10	8	5	9,3
17	CÓRDOBA	6	7	9	11	12	13	14	13	12	11	9	6	10,3
18	LA CORUÑA	8	9	11	13	14	15	16	15	14	13	11	8	12,3
19	CUENCA	4	5	7	9	10	11	12	11	10	9	7	4	8,3
20	GERONA	6	7	9	11	12	13	14	13	12	11	9	6	10,3
21	GRANADA	6	7	9	11	12	13	14	13	12	11	9	6	10,3
22	GUADALAJARA	6	7	9	11	12	13	14	13	12	11	9	6	10,3
23	GUIPÚZCOA	8	9	11	13	14	15	16	15	14	13	11	8	12,3
24	HUELVA	8	9	11	13	14	15	16	15	14	13	11	8	12,3
25	HUESCA	5	6	8	10	11	12	13	12	11	10	8	5	9,3
26	JAÉN	8	9	11	13	14	15	17	16	14	13	11	7	12,3
27	LEÓN	4	5	7	9	10	11	12	11	10	9	7	4	8,3
28	LÉRIDA	5	6	8	10	11	12	13	12	11	10	8	5	9,3
29	LUGO	6	7	9	11	12	13	14	13	12	11	9	6	10,3
30	MADRID	6	7	9	11	12	13	14	13	12	11	9	6	10,3
31	MÁLAGA	8	9	11	13	14	15	16	15	14	13	11	8	12,3
32	MELILLA	8	9	11	13	14	15	16	15	14	13	11	8	12,3
33	MURCIA	8	9	11	13	14	15	16	15	14	13	11	8	12,3
34	NAVARRA	5	6	8	10	11	12	13	12	11	10	8	5	9,3
35	ORENSE	5	7	9	11	12	13	14	13	12	11	9	6	10,2
36	PALENCIA	5	6	8	10	11	12	13	12	11	10	8	5	9,3
37	LAS PALMAS	8	9	11	13	14	15	16	15	14	13	11	8	12,3
38	PONTEVEDRA	8	9	11	13	14	15	16	15	14	13	11	8	12,3
39	LA RIOJA	6	7	9	11	12	13	14	13	12	11	9	6	10,3
40	SALAMANCA	5	6	8	10	11	12	13	12	11	10	8	5	9,3
41	S.C. TENERIFE	8	9	11	13	14	15	16	15	14	13	11	8	12,3
42	SEGOVIA	4	5	7	9	10	11	12	11	10	9	7	4	8,3
43	SEVILLA	8	9	11	13	14	15	16	15	14	13	11	8	12,3
44	SORIA	4	5	7	9	10	11	12	11	10	9	7	4	8,3
45	TARRAGONA	6	7	9	11	12	13	14	13	12	11	9	6	10,3
46	TERUEL	4	5	7	9	10	11	12	11	10	9	7	4	8,3
47	TOLEDO	6	7	9	11	12	13	14	13	12	11	9	6	10,3
48	VALENCIA	8	9	11	13	14	15	16	15	14	13	11	8	12,3
49	VALLADOLID	5	6	8	10	11	12	13	12	11	10	8	5	9,3
50	VIZCAYA	6	7	9	11	12	13	14	13	12	11	9	6	10,3
51	ZAMORA	5	6	8	10	11	12	13	12	11	10	8	5	9,3
52	ZARAGOZA	5	6	8	10	11	12	13	12	11	10	8	5	9,3

(CENSOLAR)

Table IV.C.3. Average air temperature of main cities of Spain [ºC].

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1	ÁLAVA	7	7	11	12	15	19	21	21	19	15	10	7	13,7
2	ALBACETE	6	8	11	13	17	22	26	26	22	16	11	7	15,4
3	ALICANTE	13	14	16	18	21	25	28	28	26	21	17	14	20,1
4	ALMERÍA	15	15	16	18	21	24	27	28	26	22	18	16	20,5
5	ASTURIAS	9	10	11	12	15	18	20	20	19	16	12	10	14,3
6	ÁVILA	4	5	8	11	14	18	22	22	18	13	8	5	12,3
7	BADAJOZ	11	12	15	17	20	25	28	28	25	20	15	11	18,9
8	BALEARES	12	13	14	17	19	23	26	27	25	20	16	14	18,8
9	BARCELONA	11	12	14	17	20	24	26	26	24	20	16	12	18,5
10	BURGOS	5	6	9	11	14	18	21	21	18	13	9	5	12,5
11	CÁCERES	10	11	14	16	19	25	28	28	25	19	14	10	18,3
12	CÁDIZ	13	15	17	19	21	24	27	27	25	22	18	15	20,3
13	CANTABRIA	11	11	14	14	16	19	21	21	20	17	14	12	15,8
14	CASTELLÓN	13	13	15	17	20	24	26	27	25	21	16	13	19,2
15	CEUTA	15	15	16	17	19	23	25	26	24	21	18	16	19,6
16	CIUDAD REAL	7	9	12	15	18	23	28	27	20	17	11	8	16,3
17	CÓRDOBA	11	13	16	18	21	26	30	30	26	21	16	12	20
18	LA CORUÑA	12	12	14	14	16	19	20	21	20	17	14	12	15,9
19	CUENCA	5	6	9	12	15	20	24	23	20	14	9	6	13,6
20	GERONA	9	10	13	15	19	23	26	25	23	18	13	10	17
21	GRANADA	9	10	13	16	18	24	27	27	24	18	13	9	17,3
22	GUADALAJARA	7	8	12	14	18	22	26	26	22	16	10	8	15,8
23	GUIPÚZCOA	10	10	13	14	16	19	21	21	20	17	13	10	15,3
24	HUELVA	13	14	16	20	21	24	27	27	25	21	17	14	19,9
25	HUESCA	7	8	12	15	18	22	25	25	21	16	11	7	15,6
26	JAÉN	11	11	14	17	21	26	30	29	25	19	15	10	19
27	LEÓN	5	6	10	12	15	19	22	22	19	14	9	6	13,3
28	LÉRIDA	7	10	14	15	21	24	27	27	23	18	11	8	17,1
29	LUGO	8	9	11	13	15	18	20	21	19	15	11	8	14
30	MADRID	6	8	11	13	18	23	28	26	21	15	11	7	15,6
31	MÁLAGA	15	15	17	19	21	25	27	28	26	22	18	15	20,7
32	MELILLA	15	15	16	18	21	25	27	28	26	22	18	16	20,6
33	MURCIA	12	12	15	17	21	25	28	28	25	20	16	12	19,3
34	NAVARRA	7	7	11	13	16	20	22	23	20	15	10	8	14,3
35	ORENSE	9	9	13	15	18	21	24	23	21	16	12	9	15,8
36	PALENCIA	5	7	10	13	16	20	23	23	20	14	9	6	13,8
37	LAS PALMAS	20	20	21	22	23	24	25	20	26	25	23	21	22,5
38	PONTEVEDRA	11	12	14	16	18	20	22	23	20	17	14	12	16,6
39	LA RIOJA	7	9	12	14	17	21	24	24	21	16	11	8	15,3
40	SALAMANCA	6	7	10	13	16	20	24	23	20	14	9	6	14
41	S.C. TENERIFE	19	20	20	21	22	24	26	27	26	25	23	20	22,8
42	SEGOVIA	4	6	10	12	15	20	24	23	20	14	9	5	13,5
43	SEVILLA	11	13	14	17	21	25	29	29	24	20	16	12	19,3
44	SORIA	4	6	9	11	14	19	22	22	18	13	8	5	12,6
45	TARRAGONA	11	12	14	16	19	22	25	26	23	20	15	12	17,9
46	TERUEL	5	6	9	12	16	20	23	24	19	14	9	6	13,6
47	TOLEDO	8	9	13	15	19	24	28	27	23	17	12	8	16,9
48	VALENCIA	12	13	15	17	20	23	26	27	24	20	16	13	18,8
49	VALLADOLID	4	6	9	12	17	21	24	23	18	13	8	4	13,3
50	VIZCAYA	10	11	12	13	16	20	22	22	20	16	13	10	15,4
51	ZAMORA	6	7	11	13	16	21	24	23	20	15	10	6	14,3
52	ZARAGOZA	8	10	13	16	19	23	26	26	23	17	12	9	16,8

(CENSOLAR)

Table IV.C.4. Standard climate values for Madrid.

Period: 1971-2000 - **Altitude (m):** 667
Latitude: 40° 24' 43'' N - **Longitude:** 3° 40' 41'' W - **Position:** See location ▸

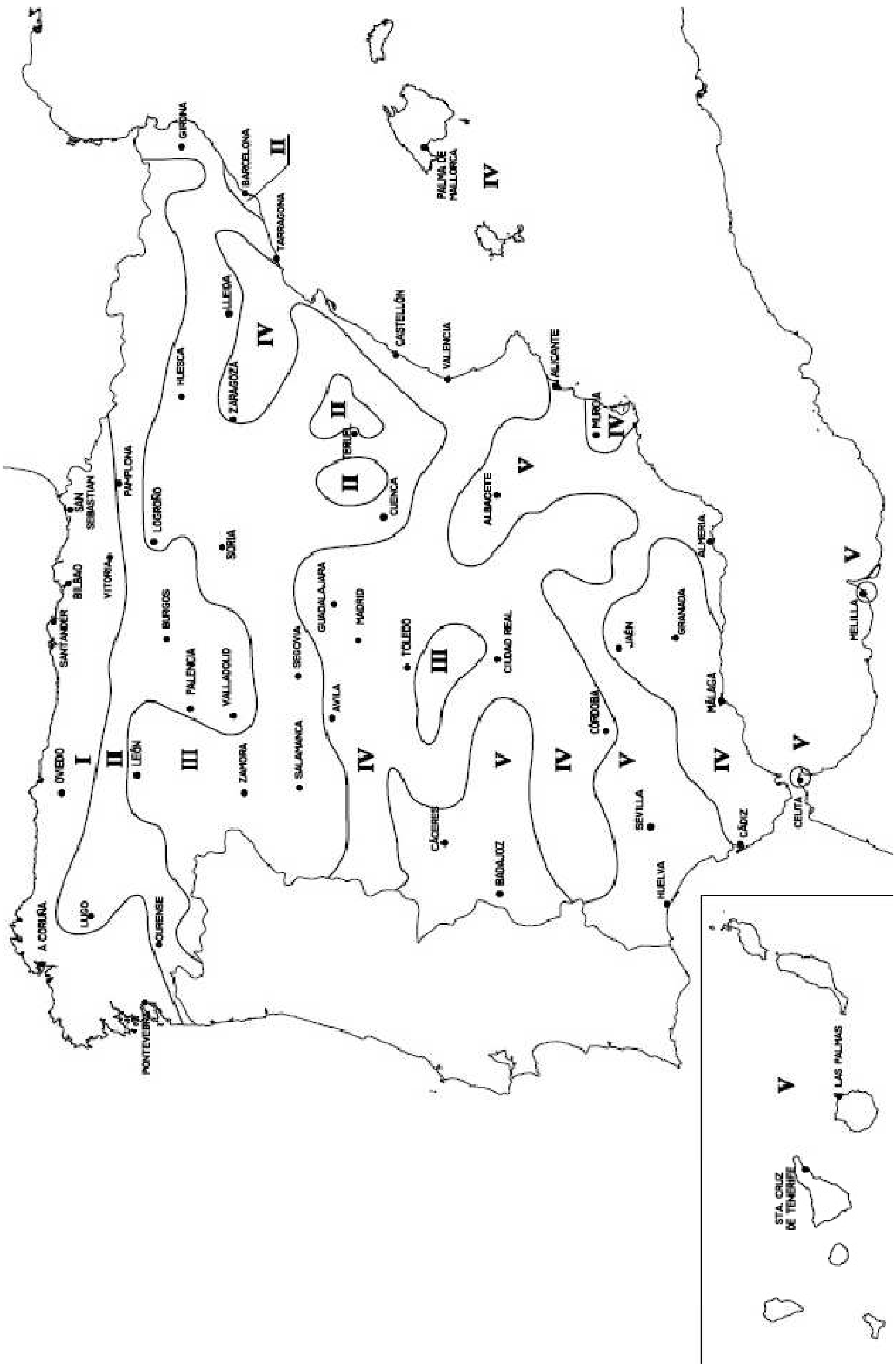
Month	T	TM	Tm	R	H	DR	DN	DT	DF	DH	DD	I
January	6.1	9.7	2.6	37	71	6	1	0	5	6	8	148
February	7.9	12.0	3.7	35	65	6	1	0	4	3	6	157
March	10.7	15.7	5.6	26	54	5	0	1	2	1	7	214
April	12.3	17.5	7.2	47	55	7	0	1	1	0	5	231
May	16.1	21.4	10.7	52	54	8	0	3	0	0	4	272
June	21.0	26.9	15.1	25	46	4	0	3	0	0	8	310
July	24.8	31.2	18.4	15	39	2	0	3	0	0	16	359
August	24.4	30.7	18.2	10	41	2	0	2	0	0	14	335
September	20.5	26.0	15.0	28	50	3	0	2	0	0	9	261
October	14.6	19.0	10.2	49	64	6	0	1	1	0	6	198
November	9.7	13.4	6.0	56	70	6	0	0	5	1	7	157
December	7.0	10.1	3.8	56	74	7	1	0	6	4	7	124
Year	14.6	19.4	9.7	436	57	63	4	16	24	16	97	2769

Key

T Monthly/Annual average temperatures (°C)
TM Monthly/Annual average of maximum daily temperatures (°C)
Tm Monthly/Annual average of minimum daily temperatures (°C)
R Monthly/Annual average rainfall (mm)
H Average relative humidity (%)
DR Monthly/Annual average number of rainfall days equal or greater to 1mm
DN Monthly/Annual average number of snow days
DT Monthly/Annual average number of stormy days
DF Monthly/Annual average number of foggy days
DH Monthly/Annual average number of frosty days
DD Monthly/Annual average number of cloudless days
I Monthly/Annual average number of hours of sunshine

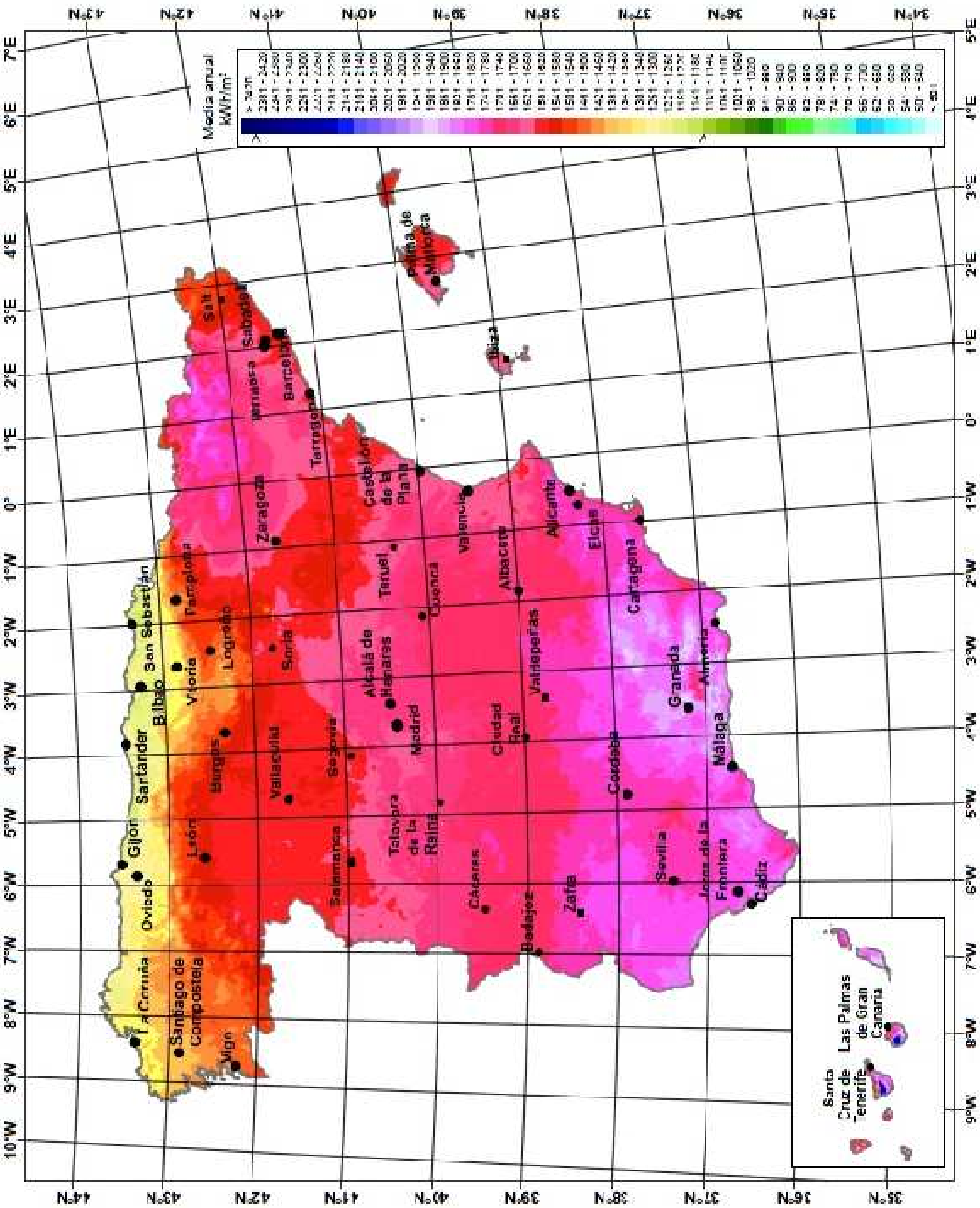
(AEMET, 2010)

Figure IV.C.1. Climatic zones in Spain.



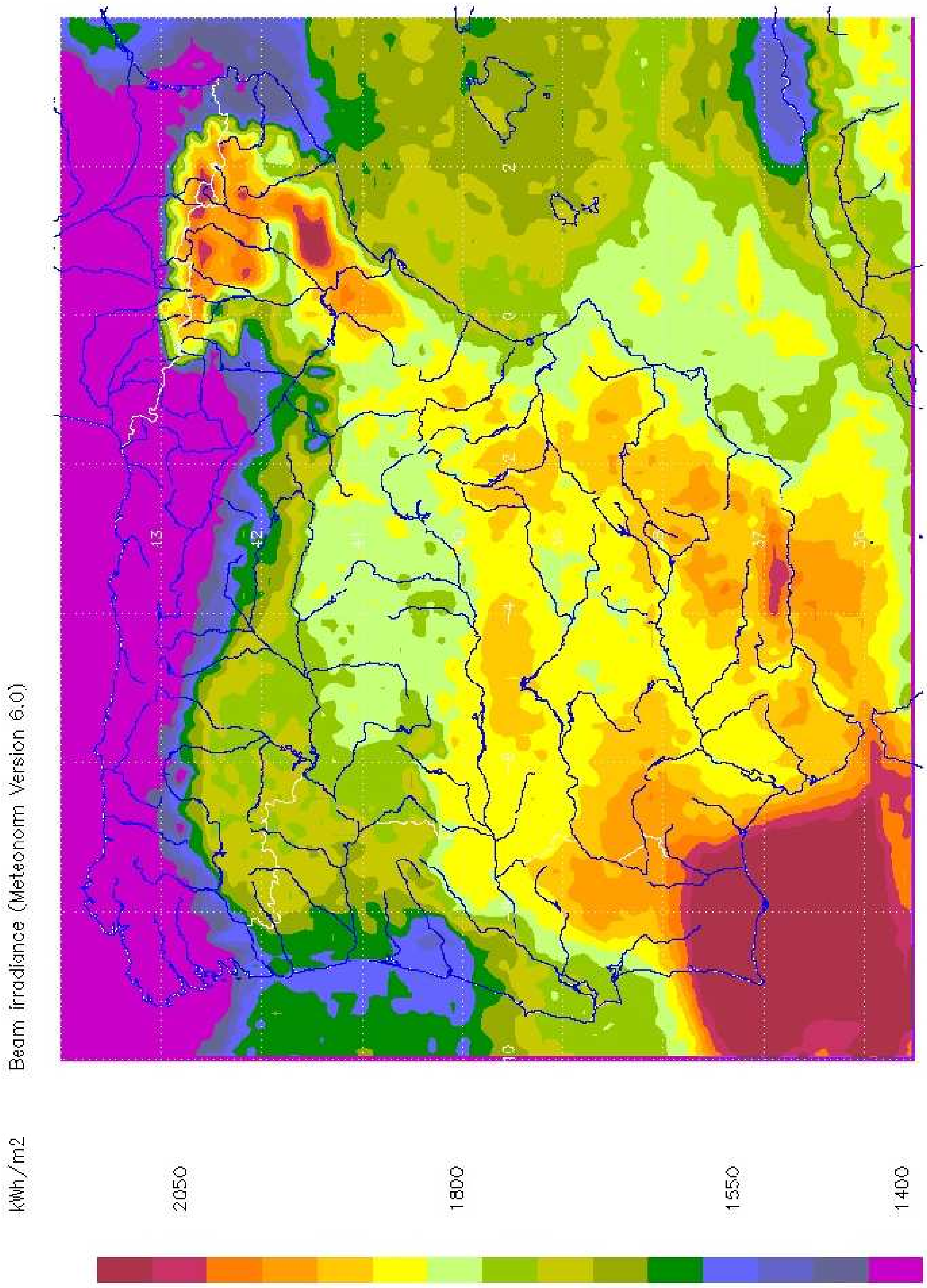
(CTE, 2009)

Figure IV.C.2. Annual global irradiance in Spain



(Meteotest, 2008)

Figure IV.C.3. Annual beam radiation in Spain.



(Meteotest, 2008)

Appendix V: EU Statistics

Appendix V.A: Housing statistics in EU

To be able to understand the tables, some abbreviations must be explained:

1) **Countries**
   - AT Austria
   - BE Belgium
   - BG Bulgaria
   - CY Cyprus
   - CZ Czech Republic
   - DE Germany
   - DK Denmark
   - EE Estonia
   - ES Spain
   - FI Finland
   - FR France
   - GR Greece
   - HU Hungary
   - IE Ireland
   - IT Italy
   - LT Lithuania
   - LU Luxembourg
   - LV Latvia
   - MT Malta
   - NL Netherlands
   - PL Poland
   - PT Portugal
   - RO Romania
   - SE Sweden
   - SI Slovenia
   - SK Slovak Republic
   - UK United Kingdom
   - EU-15 15 European countries which have joined Europe before 2004 (AT, BE, DK, FI, FR, DE, GR, IE,IT, LU, NL, PT, ES, SE, UK)
   - EU-10 European countries which have joined Europe after 2004 (CY, CZ, EE, HU, LV, LT, MT, PL, SK, SL)
   - EU-25 15 European countries plus 10 which have joined Europe after 2004
   - EU-27 EU-25 plus two countries which have joined Europe from 1 January 2007 (BG and RO)
2) **Symbols**
   - Na: not available
   - blank space: the editors have used blank spaces if the countries did not provide data and did not explicitly state that these data were unavailable.
   - nap: not applicable
   - p: provisional value

Table V.A.1. Distribution of household size (%).

	1 person			2 persons			3 persons			4 persons			5+ persons		
	1981	2004	2008	1981	2004	2008	1981	2004	2008	1981	2004	2008	1981	2004	2008
Austria [1]	26	34	36	26	28	28	17	17	16	16	14	13	14	8	7
Belgium	23	33	34	30	31	32	20	16	15	16	13	13	11	7	7
Bulgaria															
Cyprus	10	na		22	na		17	na		26	na		25	na	
Czech Republic	24	na		26	na		19	na		22	na		9	na	
Denmark [2]	30	38	39	31	33	33	16	12	12	16	12	11	7	5	5
Estonia	33	32	33	29	30	30	19	18	20	13	14	12	6	7	5
Finland	27	39	41	26	32	33	19	13	12	18	10	9	10	6	5
France	24	33	34	29	32	32	18	28 [3]	15	16		13	12	7	6
Germany [4]	31	37	39	29	34	34	17	14	13	14	11	10	9	4	4
Greece	15	21	na	25	28	na	20	21	na	24	20	na	16	10	na
Hungary	20	29		28	30		22	19		19	15		11	8	
Ireland	17	22		20	26		15	18		15	17		32	18	
Italy	18	25	28	24	26	27	22	22	22	22	20	19	14	7	4
Latvia	na	24	na	na	30	na	na	23	na	na	15	na	na	8	na
Lithuania	na	na		na	na		na	na		na	na		na	na	
Luxembourg	20	29	29	29	28	28	21	17	17	18	16	21	12	10	5
Malta	13	14	19	21	22	26	22	24	22	25	27	22	19	13	11
Netherlands	21	34	36	29	33	33	16	13	12	21	14	13	13	6	6
Poland	17	25		22	23		23	20		21	18		17	14	
Portugal	13	17		23	28		23	25		20	20		21	10	
Romania	na	18	18	na	26	27	na	22	23	na	19	20	na	14	13
Slovak Republic	18	26	na	22	22	na	19	18	na	23	21	na	18	14	na
Slovenia	17	na		18	na		22	na		24	na		19	na	
Spain	10	14	18	22	28	29	20	24	26	22	24	20	26	10	6
Sweden [5]	33	46	44	31	28	30	15	10	11	15	11	11	6	5	4
United Kingdom [6]	22	29	29	31	35	35	17	16	16	18	13	14	11	7	6

(Dol & Haffner, September 2010)

*Table V.A.2. Dwelling stock by type of building (*1,000)*

	1980[1]			1990[2]			2000[3]			2004[4]			2009[5]		
	T	MF	OF	T	MF	OF	T	MF	OF	T	MF	OF	T	MF	OF
Austria [6,7]	3,052	1,573	1,479	3,393	17	1,693	3,858	1,977	1,881	3,429	1,734	1,695	3,598	1,854	1,744
Belgium	3,811	na	na	3,882	na	na	na	na	na	4,820	na	na	5,043	1,430	3,613
Bulgaria	na	na	na	na	na	na	na	na	na	na	na	na			
Cyprus [8]	169	81	87	232	122	110	288	na	na	na	na	na			
Czech Republic [9]	3,495	1,890	1,605	3,706	2,181	1,525	3,828	2,196	1,632	na	na	na	na	na	na
Denmark	2,320	915	1,197	2,573	951	1,381	2,726	1,003	1,467	2,778	1,028	1,513	2,680	1,087	1,594
Estonia	519	na	na	647	na	na	622	na	na	626	567	59	651	na	na
Finland	1,838	1,012	826	2,210	1,275	935	2,512	1,493	1,014	2,572	1,583	1,052	2,784	1,659	1,126
France	24,717	10,957	13,730	26,976	11,721	15,255	28,221	12,281	15,940	29,495	12,734	16,761	31,264	13,642	17,622
Germany [10,11]	24,406	na	na	26,327	18,575	7,752	37,630	27,227	10,402	38,587	27,675	10,912	39,268	27,962	11,306
Greece	3,999	na	na	4,652	na	na	5,465	na	na	na	na	na	na	na	na
Hungary	3,542	na	na	3,853	na	na	4,043	1,674	2,369	4,134	na	na	4,303		
Ireland	901	na	na	1,162	na	na	1,406	na	na	1,619	na	na			
Italy	na	na	na	na	na	na	27,269	20,367	6,902	na	na	na			
Latvia	772	na	na	953	753	200	941	706	235	987	704	283	1,042	744	298
Lithuania	na	na	na	1,159	na	na	1,356	na	na	1,292	na	na	1,308		
Luxembourg	na	na	na	na	na	na	na	na	na	176	55	119	189	69	120
Malta	107	na	na	na	na	na	127	na	na	na	na	na	139		
Netherlands	4,840	na	na	5,802	na	na	6,651	na	na	6,810	1,068	4,842	7,107	2,060	5,047
Poland	9,794	na	na	11,022	na	na	11,845	na	na	12,683	na	na	13,150		
Portugal	na	na	na	na	na	na	5,005	na	na	5,310	na	na	5,537		
Romania	na	na	na	8,006	na	na	7,908	na	na	8,176	na	na	8,329		
Slovak Republic [7,12]	1,414	587	827	1,618	806	812	1,665	845	820	1,711	na	na	1,767		
Slovenia [11]	na	na	na	695	na	na	777	417	361	798	na	na			
Spain [11]	1,458	na	na	1,722	na	na	14,184	9,777	4,407	na	na	na	25,129		
Sweden [6]	3,670	2,043	1,626	4,045	2,171	1,874	4,294	2,331	1,963	4,380	2,382	1,997	4,503	2,461	2,042
United Kingdom	21,517	na	na	23,383	na	na	25,283	na	na	23,500	na	na			

T = Total, MF = Multi-family and OF = One-family
1. AT = 1981; FR = 1984
2. AT, CZ = 1991; CY, FR = 1992
3. AT, CY, CZ, IT, HU, SK = 2001; IT, FR, SI, ES = 2002
4. AT, BE, LV, LT, PT = 2003
5. FR, PT = 2006; LV, LU PL, RO SK, SE = 2008; MT = 2005

(Dol & Haffner, September 2010)

Table V.A.3. Average number of persons per household

	1980 [1]	1990 [2]	2000 [3]	2005 [4]	2007	2008	2009
Austria [5]	2.8	2.6	2.4	2.3	2.3	2.3	2.3
Belgium	2.7	na	2.4	2.3	2.3	na	na
Bulgaria							
Cyprus	3.5	3.2	3.0				
Czech Republic	2.7	2.6	2.4				
Denmark	2.5	2.3	2.2	2.2	2.2	2.2	2.2
Estonia	na	na	2.6	2.4	2.3	2.3	2.3
Finland	2.6	2.4	2.2	2.1	2.1	2.1	2.1
France [6]	2.7	2.6	2.4	2.3			
Germany [7]	2.5	2.3	2.2	2.1	2.1	2.1	na
Greece [8]	3.1	3.0	2.8	2.7			
Hungary	2.8	2.6	2.7	2.6	2.6		
Ireland	3.7	3.4	3.0	2.9			
Italy	3.0	2.8	2.6	2.5	2.4	2.4	
Latvia	na	na	2.5	2.5	2.5	2.5	2.5
Lithuania	na	na	2.6				
Luxembourg	2.8	2.6	2.5	2.5		2.5	
Malta [9]	na	na	3.0	2.9	2.9	2.9	na
Netherlands	2.8	2.4	2.3	2.3	2.3	2.2	2.2
Poland	3.1	3.1	2.9	3.1			
Portugal	3.3	3.1	2.8			2.8	
Romania				2.9	2.9	2.9	
Slovak Republic	3.0	2.9	2.6	na	na	na	na
Slovenia	3.2	3.0	2.8				
Spain	3.5	3.4	3.1	2.9	2.7	2.7	na
Sweden [10]	2.3	2.1	2.0	2.0	2.0	2.0	na
United Kingdom	2.7	2.5	2.4	2.4			

1. BE, GR = 1981; CY, FR = 1982, PL = 1978
2. CY = 1992; CZ, GR, LU, SK = 1991; PL = 1988
3. CZ, GR, SK, ES = 2001; FR = 1999; PL = 2002
4. IE, GR, UK = 2004

(Dol & Haffner, September 2010)

Table V.A.4. Average number of persons per occupied dwelling

	1980 [1]	1990 [2]	2000 [3]	2004 [4]	2008 [5]
Austria	2.8	2.6	2.4	2.4	2.3
Belgium	2.6	2.6	2.4	2.0	2.3
Bulgaria					
Cyprus	0.1	3.0	2.6	na	
Czech Republic [6]	2.9	2.8	2.6	na	
Denmark	2.4	2.1	2.1	2.0	2.1
Estonia	2.8 [7]	2.4 [7]	2.5	na	2.1
Finland	2.6	2.4	2.2	2.1	2.1
France	2.8	2.6	2.5	2.4	2.3
Germany [8]	2.5	2.4	2.2	2.2	2.1
Greece	3.2	3.0	2.8	na	na
Hungary	3.1	2.7	2.5 [7]	2.5	2.3 [7]
Ireland	3.8	3.4	3.0	2.9	
Italy	3.2	2.8	2.6	na	2.4
Latvia	3.2 [7]	2.8 [7]	2.6	2.4	2.4
Lithuania	na	3.2	2.6	2.7	
Luxembourg	2.8	2.7	2.6	2.6	2.5
Malta	3.0 [7]	na	3.0	2.9	na
Netherlands	2.9	2.6	2.4	2.4	2.4
Poland	3.6	3.4	3.2	3.1	2.9
Portugal	3.0	3.2	2.9	na	
Romania	na	na	na	3.0	2.9
Slovak Republic [9]	3.1	3.0	3.0	3.2	3.1
Slovenia	3.0	2.8	2.8	2.4	
Spain	3.9	3.3	3.0	na	2.8
Sweden	2.3	2.1	2.1	2.1	2.1
United Kingdom [10]	2.7	2.5	2.3	na	

1. AT, GR, LU, PT, ES = 1981
2. AT, GR, PT, SK, ES = 1991; DE = 1987
3. BE, GR, HU, PT, SK, ES = 2001; FR, DE, LU, HU = 2002
4. DE, MT = 2005; LT = 2003
5. AT, DK, EE, FI, NL = 2009; BE = 2007; FR, DE = 2006

(Dol & Haffner, September 2010)

Table V.A.5. Average number of rooms per dwelling and per new dwelling.

	Year	Total dwelling stock	Year	Dwellings completed
Austria [1]	2009	4.1	2002	3.5
Belgium	2001	4.7		
Bulgaria				
Cyprus	2001	5.4	2003	3.0
Czech Republic	2001	2.9 [2]	2008	3.4
Denmark	2009	3.5	2003	3.4
Estonia [3]	2009	3.3	2009	3.8
Finland	2009	3.7	2009	4.2
France	2006	4.0	2006	4.1 [4]
Germany	2008	4.4	2008	4.9
Greece	2001	3.8 [5]	2001	3.1
Hungary	2010	2.6	2009	3.1
Ireland	2002	5.6	2003	5.6
Italy	2001	4.2	2007	3.4
Latvia	2008	2.5	2004	4.3
Lithuania	2003	2.5	2003	3.5
Luxembourg	2008	4.5 [6]	2001	5.2
Malta	2005	5.7 [3]		na
Netherlands	2009	4.3	2009	3.7
Poland	2008	3.7 [7]	2008	4.3
Portugal	2008	4.8 [8]	2003	4.9
Romania	2008	2.6	2008	3.4
Slovak Republic	2001	3.2 [2]	2009	3.1
Slovenia	2004	2.8	2004	3.3
Spain	2008	5.1 [6]	2003	6.0
Sweden	2008	4.2	2009	4.4
United Kingdom [9]	2001	4.7	2001	4.5

6. Estimate

(Dol & Haffner, September 2010)

Table V.A.6. Average useful floor area per dwelling and per person (m^2)

	Year	Total dwelling stock (m^2/dwelling)	Year	Dwellings completed (m^2/dwelling)	Year	Occupied dwelling stock (m^2/person)
Austria	2009	98.5 [1]	2002	101.0	2009	42.9 [1]
Belgium	2001	81.3	2005	105.0	-	na
Bulgaria	2008	63.9	2008	88.2	2008	25.2
Cyprus	-	na	2002	197.6	-	na
Czech Republic	2001	76.3 [2]	2008	107.0	2001	28.7 [2]
Denmark	2009	114.4	2008	131.5	2009	51.4
Estonia	2009	61.2	2009	100.8	2009	29.7
Finland	2009	79.4	2008	101.7	2009	38.9
France	2006	91.0 [2]	2006	99.0 [3]	2006	39.9
Germany	2006	89.9	2008	113.6	2006	42.9
Greece	2001	81.3	2001	124.6 [4]	2001	30.6
Hungary	2005	77.7	2009	88.8	2005	31.2
Ireland	2003	104.0	2003	105.0	2002	35.0
Italy	2001	96.0	2007	73.5	2001	36.5
Latvia	2008	58.5	2008	142.7	2008	27.0
Lithuania	2008	62.9	2003	106.2	2008	24.9
Luxembourg	2008	133.5 [5]	2007	180.4	2008	66.3 [5]
Malta [6]	2002	106.4	-	na	2002	34.3
Netherlands	2000	98.0	2000	115.5	2000	41.0
Poland	2008	70.2	2008	104.0	2008	24.2
Portugal	2001	83.0 [2]	2008	96.2 [5]	-	na
Romania	2008	38.7	2008	70.0	2008	15.0
Slovak Republic	2001	56.1	2009	116.2	2001	26.0
Slovenia	2004	75.6	2004	108.7	2004	30.9
Spain	2008	99.1 [5]	2008	116.0	2008	33.0
Sweden	2008	92.8	2009	99.1	2008	45.2
United Kingdom [7]	2001	86.9	1981-2001	82.7	2001	44.0 [8]

5. Estimate

(Dol & Haffner, September 2010)

Appendix V.B: Energy statistics in EU

Table V.B.1 Domestic electricity rates in the EU 2011.

– ELECTRICITY RATES FOR HOUSEHOLDS– Average amount in euro per one kilowatt-hour of electricity for domestic consumers. Incl. energy taxes & VAT.			
Prices based on consumption of 3,500 kWh/year (30% during nighttime) Effective: January, 2011		Prices based on consumption of 7,500 kWh/year (30% during nighttime) Effective: January, 2011	
Austria	€ 0.2038	Austria	€ 0.1873
Belgium	€ 0.1921	Belgium	€ 0.1775
Bulgaria	€ 0.0970	Bulgaria	€ 0.0919
Cyprus	€ 0.1764	Cyprus	€ 0.1746
Czech Rep,	€ 0.1557	Czech Rep,	€ 0.1257
Denmark	€ 0.2632	Denmark	€ 0.2323
Estonia	€ 0.1010	Estonia	€ 0.0934
Finland	€ 0.1401	Finland	€ 0.1192
France	€ 0.1305	France	€ 0.1135
Germany	€ 0.2455	Germany	€ 0.2272
Greece	€ 0.1139	Greece	€ 0.1142
Hungary	€ 0.1798	Hungary	€ 0.1621
Ireland	€ 0.1855	Ireland	€ 0.1763
Italy	€ 0.2085	Italy	€ 0.2782
Latvia	€ 0.1207	Latvia	€ 0.1131
Lithuania	€ 0.1061	Lithuania	€ 0.0954
Luxembourg	€ 0.2011	Luxembourg	€ 0.1817
Malta	€ 0.1580	Malta	€ 0.1511
Netherlands	€ 0.1952	Netherlands	€ 0.2518
Poland	€ 0.1457	Poland	€ 0.1347
Portugal	€ 0.1779	Portugal	€ 0.1534
Romania	€ 0.1084	Romania	€ 0.1005
Slovakia	€ 0.1630	Slovakia	€ 0.1656
Slovenia	€ 0.1363	Slovenia	€ 0.1210
Spain	€ 0.1855	Spain	€ 0.1696
Sweden	€ 0.1536	Sweden	€ 0.1551
United Kingdom	€ 0.1447	United Kingdom	€ 0.1259

(European Union - Europe's Energy Portal, 2011)

Table V.B.2 Domestic gas rates in the EU 2011.

– GAS PRICES FOR HOUSEHOLDS – Average amount in euro per one kilowatt-hour of gas for domestic consumers. Incl. energy taxes & VAT.			
Prices based on consumption of 15,000 kWh/year (or 1,380 m3 of gas) Effective: January, 2011		Prices based on consumption of 30,000 kWh/year (or 2,760 m3 of gas) Effective: January, 2011	
Austria	€ 0.0637	Austria	€ 0.0558
Belgium	€ 0.0473	Belgium	€ 0.0417
Bulgaria	€ 0.0384	Bulgaria	€ 0.0271
Cyprus	NO DATA	Cyprus	NO DATA
Czech Rep.	€ 0.0462	Czech Rep.	€ 0.0454
Denmark	€ 0.1054	Denmark	€ 0.1058
Estonia	€ 0.0363	Estonia	€ 0.0339
Finland	NO DATA	Finland	NO DATA
France	€ 0.0620	France	€ 0.0520
Germany	€ 0.0572	Germany	€ 0.0481
Greece	NO DATA	Greece	NO DATA
Hungary	€ 0.0519	Hungary	€ 0.0512
Ireland	€ 0.0498	Ireland	€ 0.0422
Italy	€ 0.0542	Italy	€ 0.0469
Latvia	€ 0.0265	Latvia	€ 0.0325
Lithuania	€ 0.0439	Lithuania	€ 0.0314
Luxembourg	€ 0.0470	Luxembourg	€ 0.0392
Malta	NO DATA	Malta	NO DATA
Netherlands	€ 0.0702	Netherlands	€ 0.0709
Poland	€ 0.0562	Poland	€ 0.0456
Portugal	€ 0.0612	Portugal	€ 0.0594
Romania	€ 0.0265	Romania	€ 0.0257
Slovakia	€ 0.0522	Slovakia	€ 0.0509
Slovenia	€ 0.0435	Slovenia	€ 0.0388
Spain	€ 0.0506	Spain	€ 0.0435
Sweden	€ 0.1098	Sweden	€ 0.0987
United Kingdom	€ 0.0436	United Kingdom	€ 0.0407

(European Union - Europe's Energy Portal, 2011)

Table V.B.3 Natural gas prices for households.

Country	National Currency	2008	2009	1Q2008	2Q2008	3Q2008	4Q2008	1Q2009	2Q2009	3Q2009	4Q2009
Canada	Canadian Dollar	547	..	433	517	674	565	566	457	..	..
Mexico	Mexican Pesos	4 995	5 679	4 733	4 766	4 946	5 534	5 820	5 879	5 604	5 414
United States	US Dollar	533	460	484	609	757	520	467	471	567	415
Austria	Euro	701	750	680	680	680	762	792	748	744	716
Belgium	Euro	764	652	681	681	847	847	704	704	600	600
Czech Republic	Czech Crown	14 497	15 526	13 186	13 559	14 805	16 437	16 511	16 026	14 998	14 569
Denmark	Danish Crown	..	7 131	..	..	..	..	6 875	7 030	7 255	7 363
Finland	Euro	356	341	322	341	371	390	367	325	330	344
France	Euro	630	610	597	618	644	659	659	594	594	594
Germany	Euro	..	..	..	..	..	..	..	..	..	..
Greece	Euro	830	750	587	621	1 353	760	586	537	1 324	551
Hungary	Hungarian Forint	129 131	144 862	115 878	127 176	145 670	143 104	144 173	156 455	160 138	137 067
Ireland	Euro	707	732	619	665	799	746	748	750	823	607
Italy	Euro	788	763	738	737	834	844	878	878	648	648
Luxembourg	Euro	595	543	..	..	..	..	..	..	..	..
Netherlands	Euro	848	837	816	816	880	880	946	944	729	729
Norway	Norwegian Crown	x	x	x	x	x	x	x	x	x	x
Poland	Polish Zloty	2 249	2 501	1 807	2 239	2 657	2 294	2 121	2 546	3 127	2 210
Portugal	Euro	729	691	727	727	732	732	690	690	692	692
Slovak Rep.	Slovak Crown	557	562	557	557	557	557	562	562	562	562
Spain	Euro	702	666	648	681	708	773	745	669	635	616
Sweden	Swedish Crown	11 152	11 472	10 413	10 413	11 891	11 891	11 262	11 262	11 681	11 681
Switzerland	Swiss Franc	1 185	1 087	1 135	1 157	1 159	1 288	1 211	1 142	1 100	1 007
Turkey	New Turkish Lira	856	880	696	750	873	1 107	1 070	872	792	787
United Kingdom	Pound Sterling	451	513	386	410	469	538	530	509	507	506
Australia	Australian Dollar	..	..	..	..	..	..	..	..	..	..
Japan	Japanese Yen	..	..	..	..	..	..	..	..	..	..
Korea	South Korean Won	697 900	670 775	681 916	697 222	697 400	715 063	720 165	720 165	755 541	755 541
New Zealand	New Zealand Dollar	..	..	..	..	..	..	..	..	..	..

1. Average price in national currency per 10^7 kcal on a gross calorific value basis.

(IEA/OECD, 2011)

Table V.B.4 Renewable energy in final energy consumption (2020 target).

	EU Member State	2006	2007	2008	2020 Target	% To cover:	Bar Graph
1	United Kingdom	1.5 %	1.8 %	2.2 %	15 %	12.8 %	
2	Ireland	3.1 %	3.4 %	3.8 %	16 %	12.2 %	
3	France	9.6 %	10.2 %	11 %	23 %	12 %	
4	Denmark	16.8 %	18.1 %	18.7 %	30 %	11.3 %	
5	Netherlands	2.5 %	3 %	3.2 %	14 %	10.8 %	
6	Italy	5.3 %	5.2 %	6.6 %	17 %	10.4 %	
7	Latvia	31.3 %	29.7 %	29.8 %	40 %	10.2 %	
8	Greece	7.2 %	8.1 %	7.9 %	18 %	10.1 %	
9	Slovenia	15.5 %	15.6 %	15.1 %	25 %	9.9 %	
10	Malta	0.1 %	0.2 %	0.2 %	10 %	9.8 %	
	EU27	8.8 %	9.7 %	10.3 %	20 %	9.7 %	
11	Belgium	2.7 %	3 %	3.3 %	13 %	9.7 %	
12	Spain	9.1 %	9.5 %	10.7 %	20 %	9.3 %	
13	Germany	6.9 %	9 %	8.9 %	18 %	9.1 %	
14	Cyprus	2.5 %	3.1 %	4.1 %	13 %	8.9 %	
15	Luxembourg	0.9 %	2 %	2.1 %	11 %	8.9 %	
16	Lithuania	14.7 %	14.2 %	14.9 %	23 %	8.1 %	
17	Portugal	20.5 %	22.2 %	23 %	31 %	8 %	
18	Finland	29.2 %	28.9 %	30.5 %	38 %	7.5 %	
19	Poland	7.4 %	7.3 %	7.8 %	15 %	7.2 %	
20	Bulgaria	9.3 %	9.1 %	9.3 %	16 %	6.7 %	
21	Hungary	5.1 %	6 %	6.6 %	13 %	6.4 %	
22	Estonia	16.1 %	17.1 %	18.9 %	25 %	6.1 %	
23	Czech Republic	6.4 %	7.3 %	7.2 %	13 %	5.8 %	
24	Slovakia	6.2 %	7.4 %	8.3 %	14 %	5.7 %	
25	Austria	24.8 %	26.6 %	28.3 %	34 %	5.7 %	
26	Sweden	42.7 %	44.2 %	44.4 %	49 %	4.6 %	
27	Romania	17.5 %	18.7 %	20.3 %	24 %	3.7 %	

Share of renewable consumption to gross final energy consumption. Comprises of direct use of renewables (e.g. biofuels) plus energy produced from renewables (e.g. wind, hydro). Final energy consumption is the energy that households, industry, services, agriculture and the transport sector use.

(European Union - Europe's Energy Portal, 2011)

Energy statistics in Finland

Table V.B.5 Total energy consumption by source (TJ) and CO_2 emissions (Mt) in Finland.

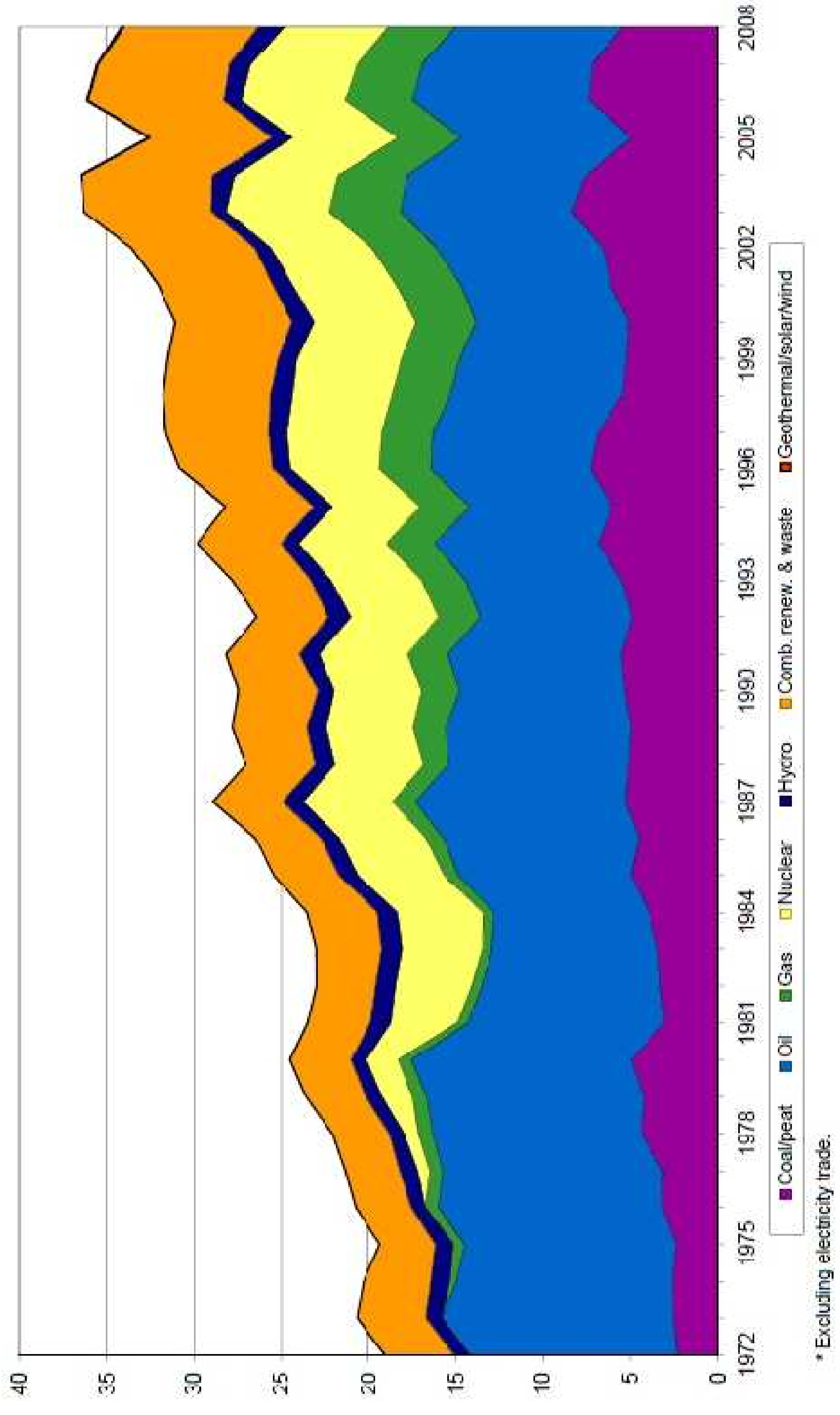
Corrected on 4 April 2011. The corrections are indicated in red, were previously 31348 and 4,2.

Energy source* 5)	**2009**	**2010***	**Yearly change -%***	**% from total consumption***
Oil	335495	353871	5,5	24,5
Coal 1)	151982	186346	22,6	12,9
Natural gas	134568	148615	10,4	10,3
Nuclear Energy 2)	246555	238733	-3,2	16,5
Net Imports of Electricity 3)	43504	37802	-13,1	2,6
Hydro and Wind Power 4)	46259	47010	1,6	3,3
Peat	71743	93544	30,4	6,5
Wood fuels	267501	307600	15,0	21,3
Others	30078	31198	3,7	2,2
Energy total consumption	**1327684**	**1444720**	**8,8**	**100**
Bunkers	31841	25988	-18,4	
CO2 emissions from energy sector	51,9	59,8	15,3	

1) Coal: includes hard coal, coke, blast furnace gas and coke oven gas.
2) Conversion of electricity generation into fuel units: Nuclear power: 10.91 TJ/GWh (33% total efficiency)
3) Conversion of electricity generation into fuel units: Hydro power, wind power and net imports of electricity: 3.6 TJ/GWh (100%)
4) Conversion of electricity generation into fuel units: Hydro power, wind power and net imports of electricity: 3.6 TJ/GWh (100%)
5) *Preliminary

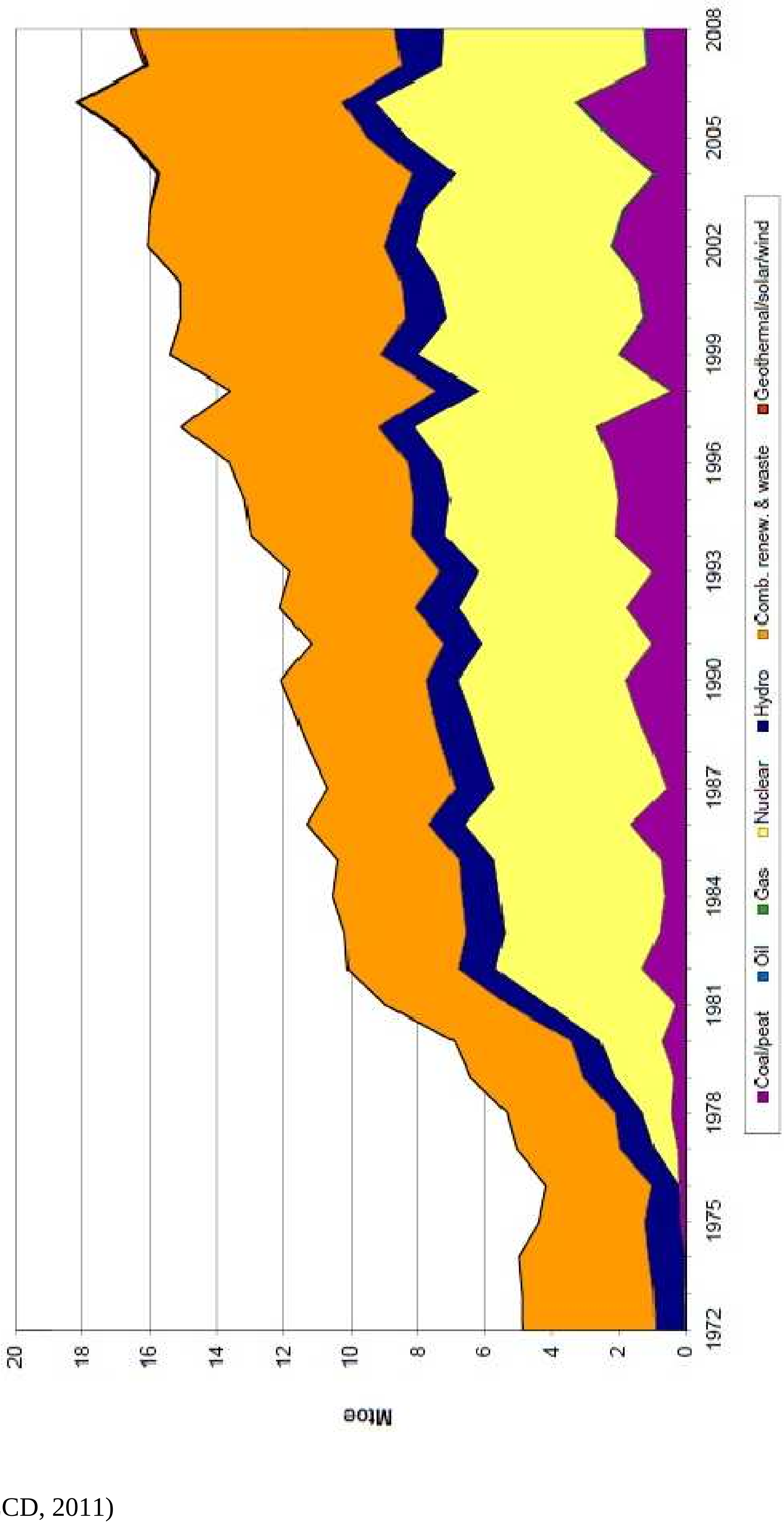
(Statistics: Energy supply, consumption and prices [e-publication], 2011)

Figure V.B.1 Total primary energy supply in Finland 1972-2008)



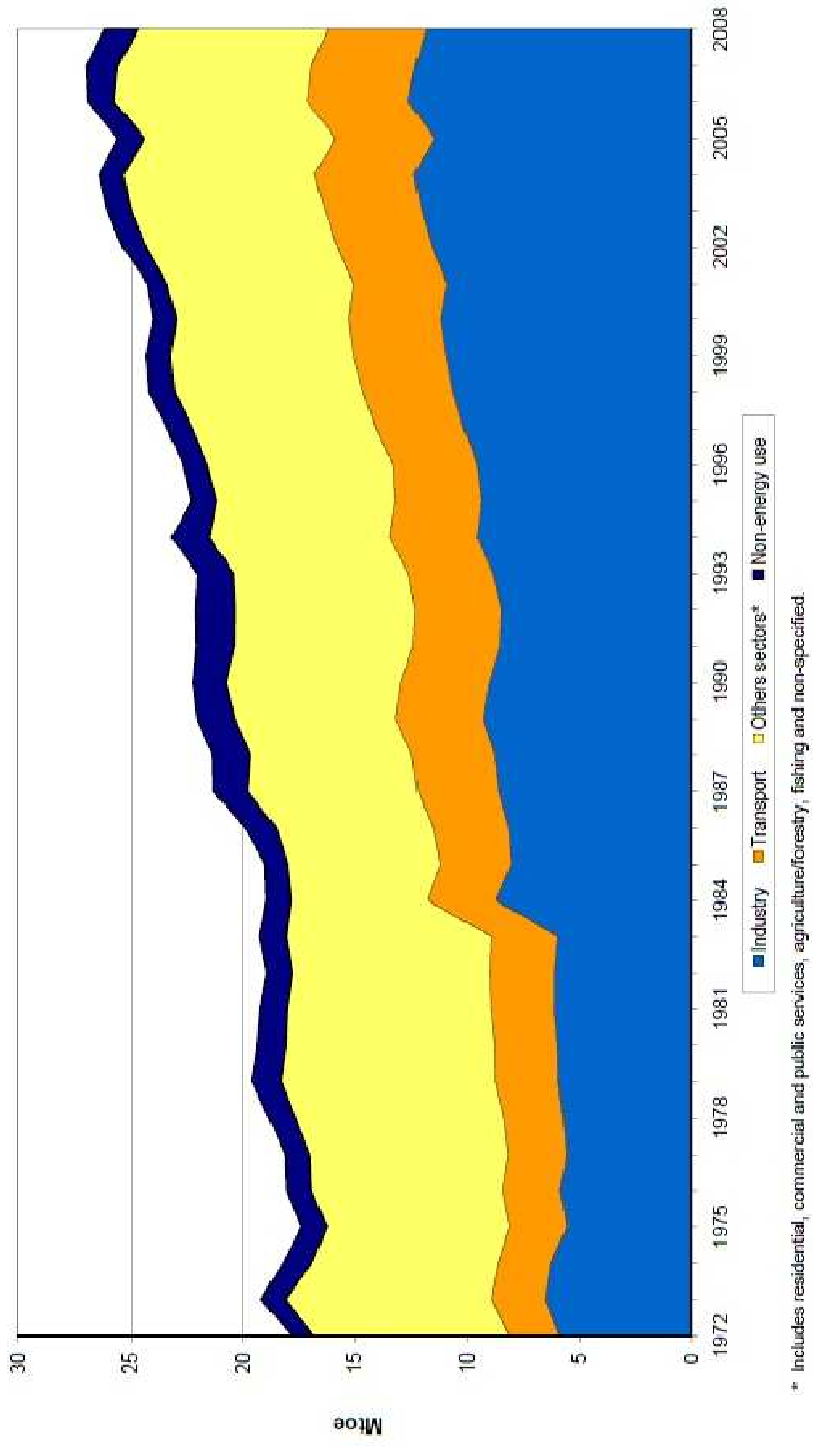
(IEA/OECD, 2011)

Figure V.B.2. Evolution of the total energy production in Finland (1972-2008)



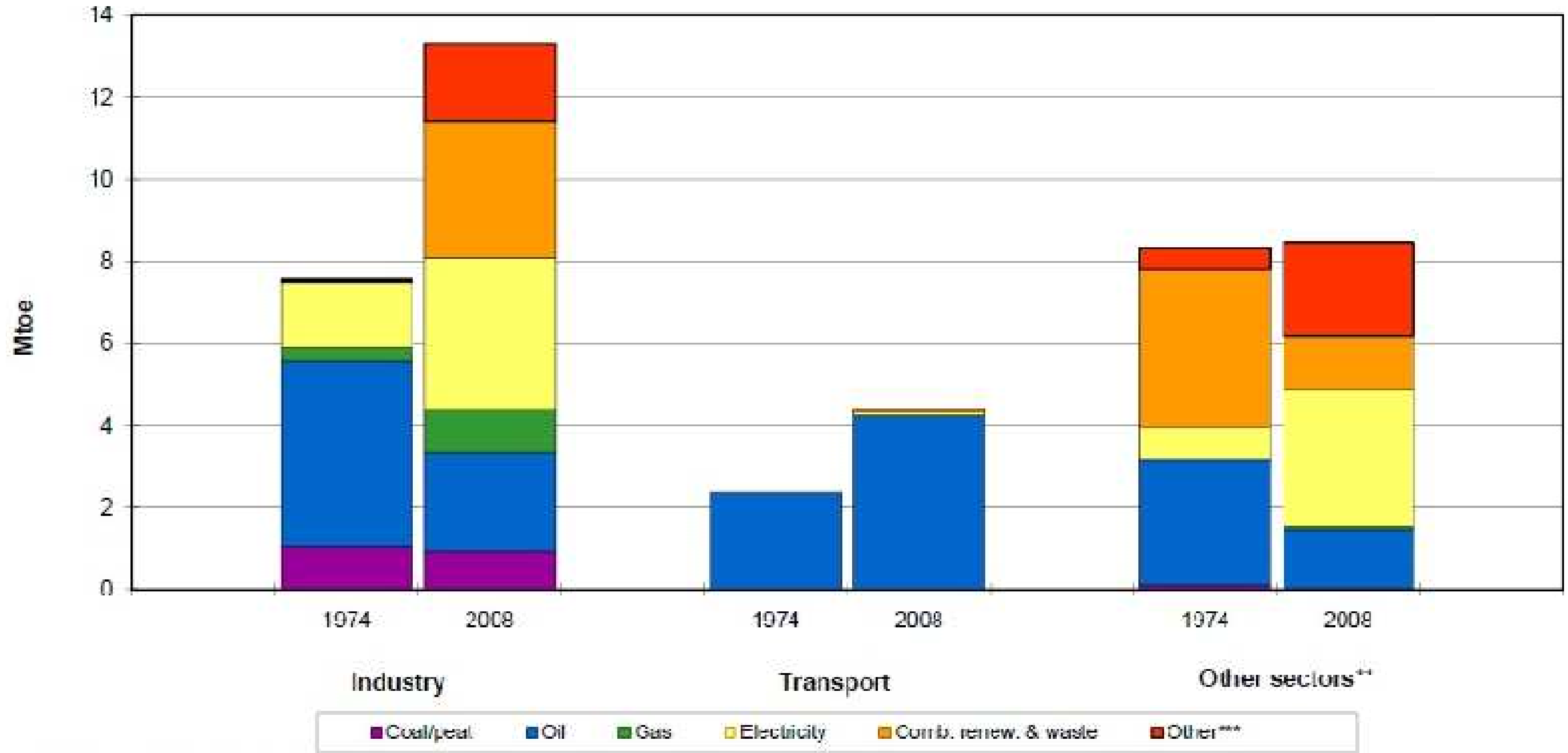
(IEA/OECD, 2011)

Figure V.B.3. Evolution of the total energy consumption by sector in Finland (1972-2008)



(IEA/OECD, 2011)

Figure V.B.4. Breakdown of sectoral final consumption by source in Finland (1974-2008)

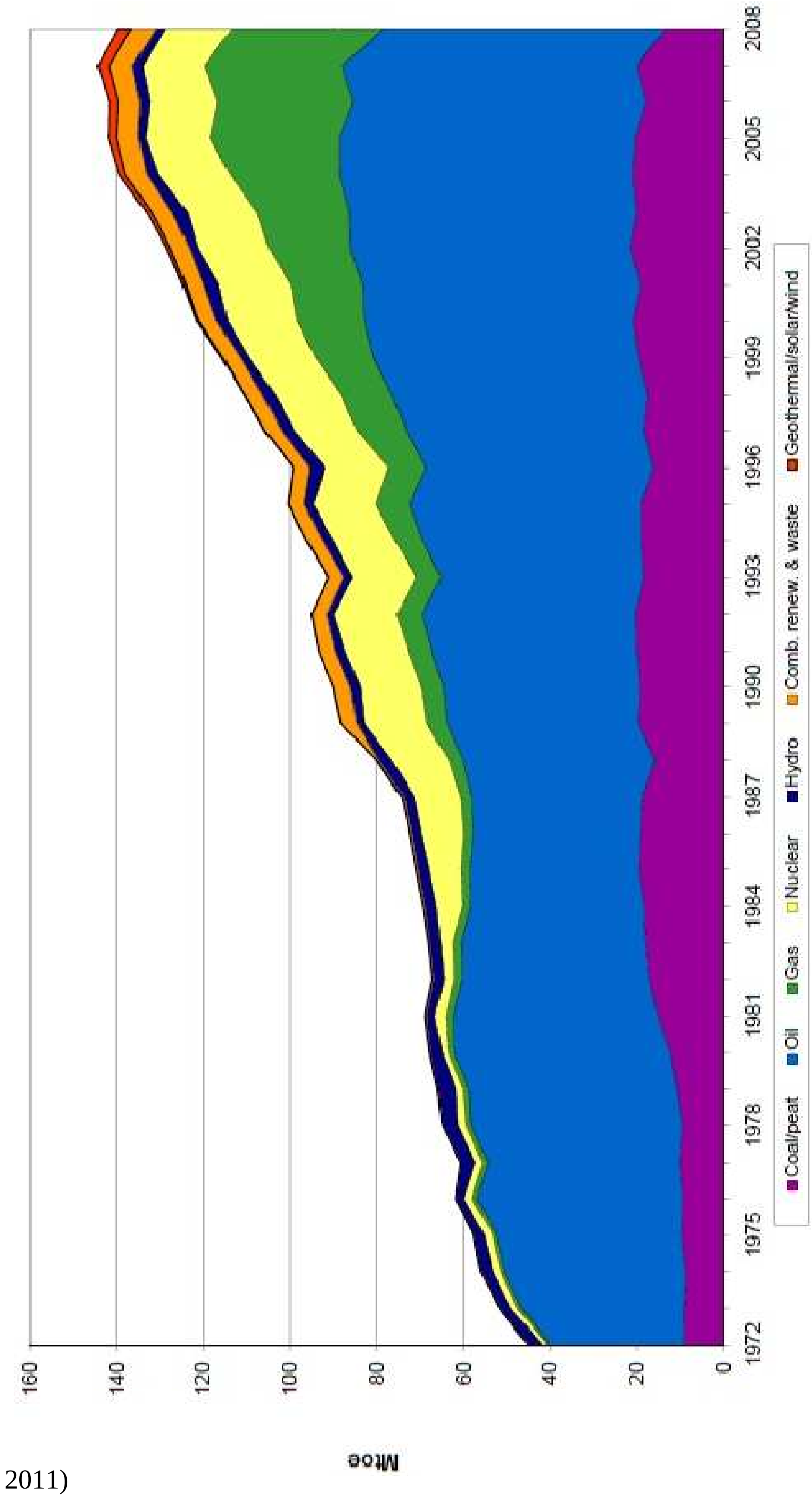


* Includes non-energy use.
** Includes residential, commercial and public services, agriculture/forestry, fishing and non-specified
*** Includes direct use of geothermal/solar thermal and heat produced in CHP/heat plants

(IEA/OECD, 2011)

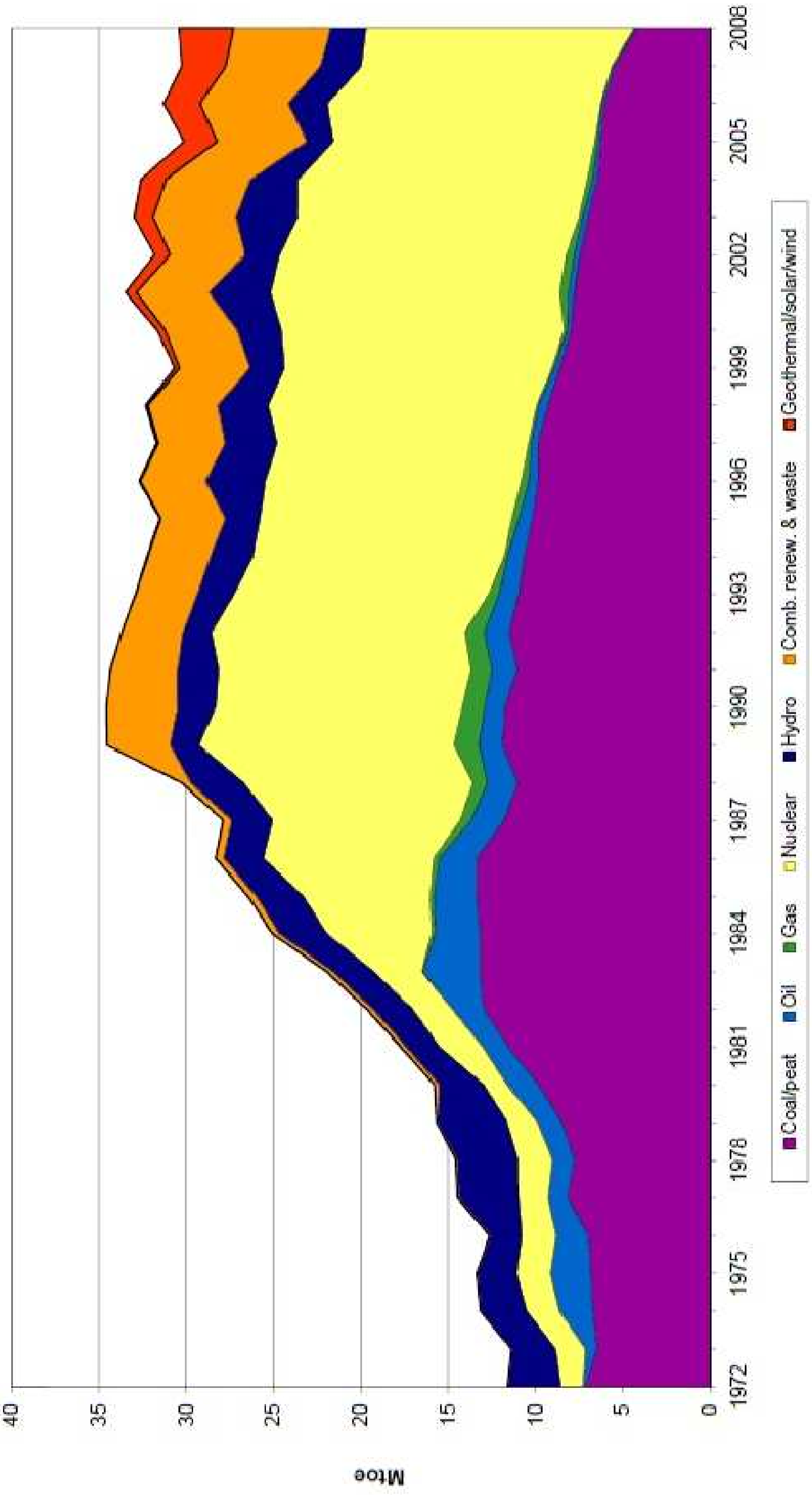
Energy statistics in Spain

Figure V.B.5. Evolution of the total primary energy supply in Spain (1972-2008)



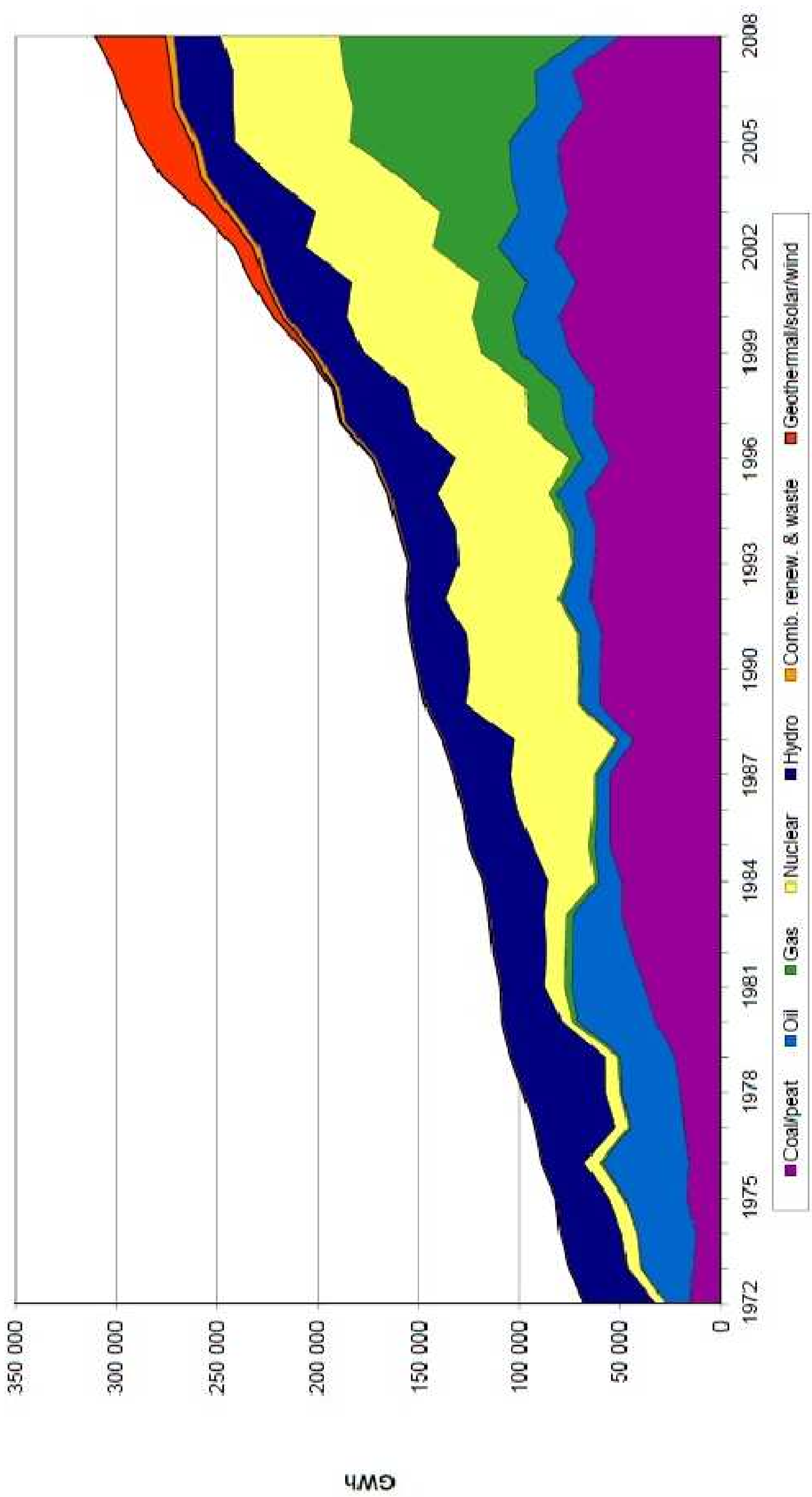
(IEA/OECD, 2011)

Figure V.B.6 Evolution of the total energy production in Spain (1972-2008)



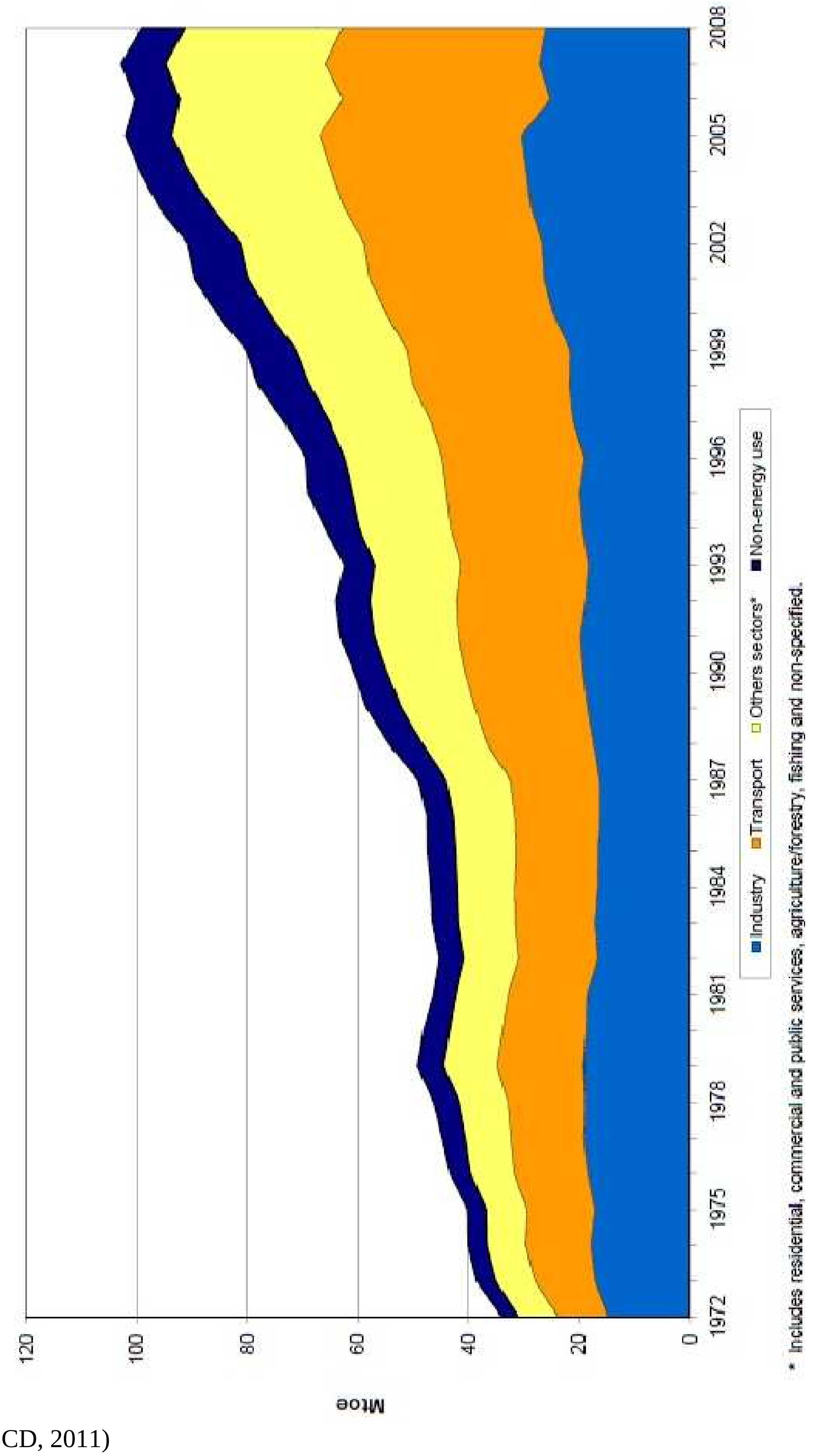
(IEA/OECD, 2011)

Figure V.B.7 Evolution of the electricity generation by fuel in Spain (1972-2008)



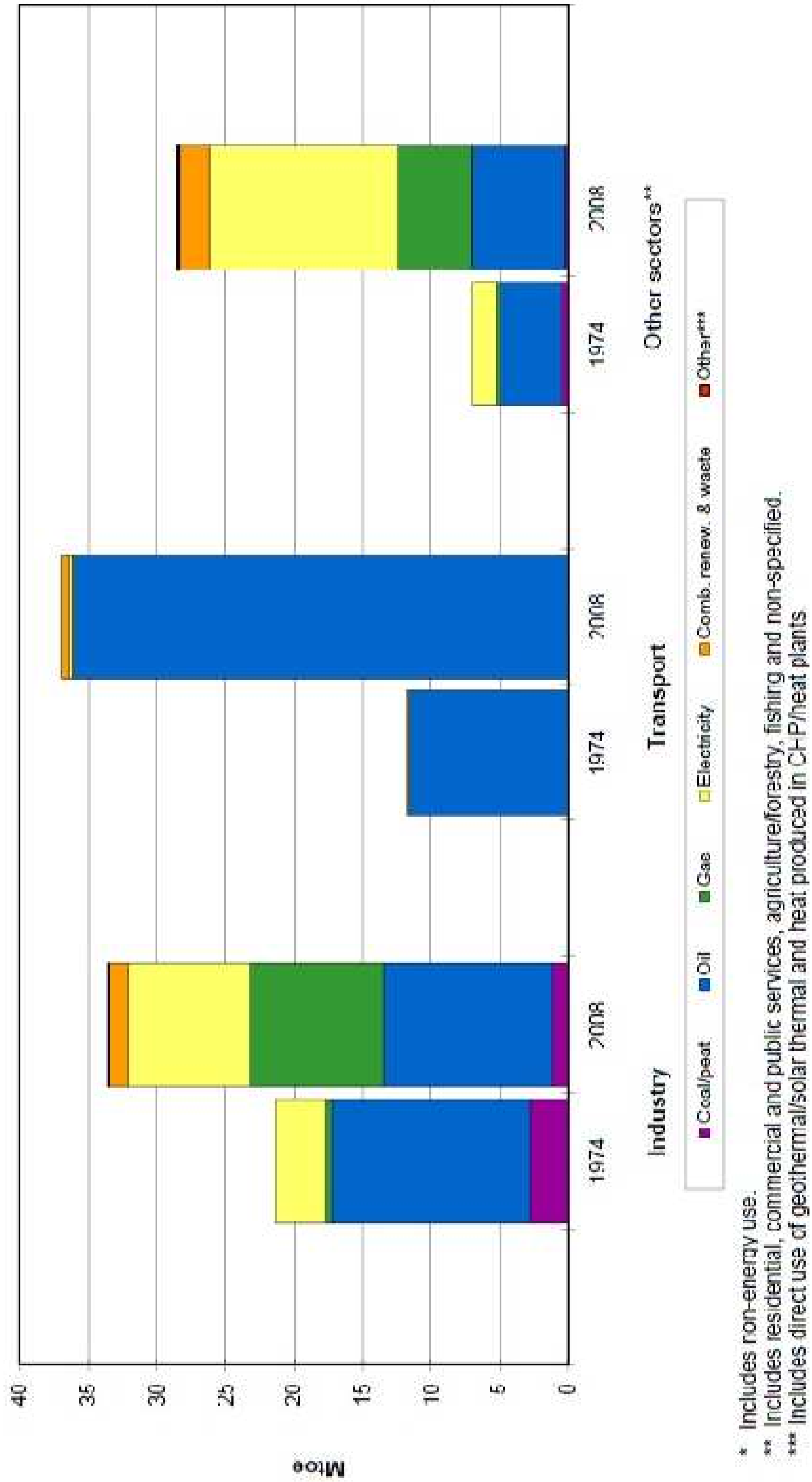
(IEA/OECD, 2011)

Figure V.B.8 Evolution of the final consumption by sector in Spain (1972-2008)



(IEA/OECD, 2011)

Figure V.B.9 Breakdown of sectoral final consumption by source in Spain (1974-2008)



(IEA/OECD, 2011)

Appendix VI: Tables and figures from analyses

Table VI.1. Climate data of Tampere (RETScreen).

Month		Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
		°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January		-6,4	89,5%	0,23	99,8	3,3	-9,4	758	0
February		-6,8	85,8%	1,00	99,9	3,1	-9,2	694	0
March		-2,8	80,4%	2,37	100,1	3,2	-4,9	645	0
April		3,3	69,2%	3,92	100,3	3,1	2,1	441	0
May		9,8	64,3%	5,43	100,4	3,1	9,8	280	0
June		14,2	67,1%	5,60	100,0	3,0	14,8	114	128
July		16,9	70,8%	5,25	100,1	2,8	16,9	34	214
August		15,0	75,1%	4,02	100,1	2,8	14,8	93	155
September		9,7	81,7%	2,52	100,1	3,0	9,4	249	0
October		4,6	87,0%	1,11	100,0	3,3	3,5	415	0
November		-0,6	91,0%	0,44	100,1	3,3	-3,0	558	0
December		-4,3	91,2%	0,14	99,8	3,3	-7,8	691	0
Annual		4,4	79,5%	2,63	100,0	3,1	3,1	4.952	495
Measured at	m					10,0	0,0		

Table VI.2. Climate data of Madrid (RETScreen).

Month	Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	6,1	79,0%	2,01	94,5	2,8	2,7	369	0
February	7,5	73,0%	2,93	94,3	2,6	4,6	294	0
March	10,0	68,0%	4,38	94,2	2,8	9,5	248	0
April	12,2	64,0%	5,41	93,9	3,1	13,5	174	66
May	16,0	61,0%	6,39	93,8	2,7	20,0	62	186
June	20,7	54,0%	7,41	93,9	2,7	27,2	0	321
July	24,4	46,0%	7,51	93,8	2,9	30,6	0	446
August	23,9	49,0%	6,59	93,8	2,9	29,0	0	431
September	20,5	59,0%	5,05	94,0	2,5	22,7	0	315
October	14,8	70,0%	3,27	94,2	2,4	14,9	99	149
November	9,4	75,0%	2,20	94,3	2,3	7,7	258	0
December	6,4	78,0%	1,64	94,5	2,5	3,8	360	0
Annual	14,4	64,6%	4,57	94,1	2,7	15,6	1.864	1.914
Measured at (m)					10,0	0,0		

Table VI.3. Iterations for slope in Tampere.

β [º]	Daily solar radiation - tilted (annual average) kWh/m²/d	Annual solar radiation - tilted: MWh/m²
31	3,36	1,23
32	3,37	1,23
33	3,38	1,24
34	3,39	1,24
35	3,40	1,24
36	3,41	1,25
37	3,42	1,25
38	3,43	1,25
39	3,43	1,25
40	3,44	1,25
41	3,45	1,26
42	3,45	1,26
43	3,45	1,26
44	3,46	1,26
45	3,46	1,26
46	3,46	1,26
47	3,46	1,26
48	3,46	1,26
49	3,46	1,26
50	3,46	1,26
51	3,46	1,26
52	3,46	1,26
53	3,45	1,26
54	3,45	1,26
55	3,45	1,26
56	3,44	1,26
57	3,43	1,25
58	3,43	1,25
59	3,42	1,25
60	3,41	1,24
61	3,40	1,24
62	3,39	1,24
63	3,38	1,23
64	3,37	1,23
65	3,35	1,22
66	3,34	1,22
67	3,33	1,21
68	3,31	1,21
69	3,30	1,20
70	3,28	1,20
71	3,26	1,19

Table VI.4. Iterations for slope in Madrid.

β [º]	Daily solar radiation - tilted (annual average) kWh/m²/d	Annual solar radiation - tilted: MWh/m²
20	5,04	1,84
21	5,06	1,85
22	5,07	1,85
23	5,08	1,85
24	5,09	1,86
25	5,10	1,86
26	5,10	1,86
27	5,11	1,87
28	5,11	1,87
29	5,12	1,87
30	5,12	1,87
31	5,12	1,87
32	5,12	1,87
33	5,12	1,87
34	5,12	1,87
35	5,12	1,87
36	5,11	1,87
37	5,11	1,86
38	5,10	1,86
39	5,09	1,86
40	5,08	1,85
41	5,07	1,85
42	5,06	1,85
43	5,05	1,84
44	5,03	1,84
45	5,02	1,83
46	5,00	1,83
47	4,98	1,82
48	4,97	1,81
49	4,95	1,81
50	4,92	1,80